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ORIGINAL CONTRIBUTION

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Longitudinal changes in body composition, physical capacities and energy expenditure in boys and girls during the onset of puberty

Summary *Background:* The onset of puberty is a period of rapid anatomical and physiological alterations expected to induce changes in metabolic rate and energy requirements of children.

Aim of the study: To evaluate the changes in anthropometrical features, body composition, physical capacities, and energy expenditure (EE) of boys and girls during the period of onset of puberty.

Methods: Sixteen children (8 boys and 8 girls were recruited in the same school-class and studied both at 10.4 and 12.8 years of age. Body composition was assessed by bioimpedance analysis. Peak oxygen uptake (peak VO_2) was measured using an automated on-line system during exercising on a cycle ergometer. Energy expenditure (EE) was determined by whole-body indirect calorimetry over a 24-h period after a 12-h period of adaptation to the calorimeters. Volunteers followed the same activity programme that included four 15-min periods of exercise.

Results: During the onset of puberty, boys and girls gained 4.7 ± 2.1 $kg.y^{-1}$ ($P < 0.0003$) fat-free mass (FFM), whereas fat mass gain was 1.0 ± 1.2 $kg.y^{-1}$ ($P < 0.05$) in girls and 0.20 ± 0.66 $kg.y^{-1}$ in boys (NS). Peak VO_2 adjusted for differences in FFM was not significantly affected by gender or pubertal stage. However, adjusted external mechanical power performed at peak VO_2 was higher in pubertal than in prepubertal children, by 40 % ($P < 0.0001$) and 22 % ($P < 0.003$) in boys and girls, respectively. It was also 17 % ($P < 0.0002$) higher in pubertal boys than in pubertal girls. Daily and sleeping EE increased by 38 % and 32 % in boys and girls, respectively, during the 2.4-y period ($P < 0.0001$). Adjusted EEs were also significantly higher in pubertal than in prepubertal boys ($P < 0.05$ and $P < 0.003$), but not in girls. The main significant determinants of daily EE were FFM ($r^2 = 0.866$, $P < 0.0001$), peak VO_2 ($r^2 = 0.017$, $P < 0.04$), and age ($r^2 = 0.014$, $P < 0.05$). Tanner's stage was an additional determinant of sleeping EE ($r^2 = 0.025$, $P < 0.006$).

Conclusions: The increases in physical capacities and EE during the onset of puberty indicated clear gender differences, which could be explained mainly by alterations of body composition in boys and girls, and by changes in hormonal status in boys. They also stressed the significant increase in energy requirements of children, especially boys, at an early stage of puberty.

Key words Children – puberty – body composition – physical capacities – energy expenditure – whole-body calorimetry

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Introduction

The period of puberty is characterised by an acceleration of somatic growth and rapid changes in body composition and hormonal status including growth spurt, impressive increase in fat-free mass (FFM), decrease in body fat content (1, 2) and increases in growth hormone (GH), insulin-like growth factor I (IGF-I), gonadotrophin, and sex steroid hormone secretion (3–8). These anatomical and physiological changes can alter energy metabolism of children during this important period of life.

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Normal pubertal development in humans begins between the ages of 9–13 years in girls, and 10–14 years in boys. We, therefore, performed a longitudinal study in boys and girls at 10.4 years (prepubertal group) and 12.8 years (pubertal group) of age to evaluate the changes in anthropometrical features, body composition, and energy expenditure (EE) during the period of onset of puberty. Body composition was assessed by using the bioimpedance analysis method and from muscle and fat arm area. EE was measured by whole-body indirect calorimetry in the same conditions and according to the same standardised activity programme.

Subjects and methods

Subjects

Sixteen healthy children (8 boys and 8 girls) participated twice in this study. The volunteers were recruited in the same school-class in the suburbs of Clermont-Ferrand, France. Before the study began, the purpose and objectives were carefully explained to each subject and his (her) parents. Written informed consent was obtained from the children and their parents. The experimental protocol was approved by the National Human Research Ethical Committee for Medical Sciences. All subjects had a thorough physical examination and a medical history was taken. Only individuals apparently healthy, not suffering from any diagnosed disease, and under no medication known to influence energy metabolism were included. Their usual activity (number of hours per week of physical training at school or in clubs, and usual types of leisure) was assessed by interview in the presence of parents. Height was measured to the nearest 0.1 cm with an anthropometric plane while the subjects were clothed and shoeless, and stood erect with their heels almost touching each other. Body weight (BW) was measured to the nearest 0.1 kg with a portable digital metric scale, which was calibrated by using standardised weights. The sexual maturity (Tanner stage) of children was assessed from secondary sexual characteristics, i. e. breast development and pubic hair in girls, and genital development, i. e. testes and penis, and pubic hair development in boys (1,9).

Determination of body composition

Body composition was assessed by bioimpedance analysis (BIA) using an impedance analyser (model BIA 101, RJL systems, Detroit, MI, USA) with four cutaneous probes, and current at 50 kHz. FFM was calculated using the prediction equation of Guo et al. (10) which takes also into account sex, and anthropometrical measurements: lateral calf skinfold, midaxillary skinfold, subscapular skinfold, and arm muscle circumference. Fat mass (FM) was calculated from body weight minus FFM weight. Total upper arm (TUA), fat (UFE), and muscle (UME) areas were derived from upper arm circumference (AC) and triceps skinfold thickness (TS) by using equations validated with magnetic resonance imaging in 9.5-year old children (11).

Assessment of physical capacities

Peak oxygen uptake (peak VO_2) was measured in all subjects using a cycle ergometer. The subjects performed several successive 3.5 min steps against increasing braking forces until exhaustion. The first step corresponded to 17.5 W. The exercise intensity was then increased by 17.5-W increments. The pedalling frequency was 70 rpm. Heart rate (HR) was recorded continuously (Scheller AG, Cardiovit CS–6/12, Baar, Switzerland). Oxygen (O_2) consumption and carbon dioxide (CO_2) production were measured continuously by open-circuit respirometry and averaged every 30 s using an automated on-line system (Medical Graphics CPX ID, St Paul, USA). The criteria for reaching peak VO_2 were a respiratory quotient higher than 1.1 and a maximal HR close to the theoretical maximal HR (220 – age (y)). External mechanical power (EMP) corresponding to the last step was recorded.

Measurement of energy expenditure

EE was measured by whole-body indirect calorimetry using two open-circuit calorimetric chambers, symmetrical and comfortably equipped (12). Volunteers spent 36 hours in the chambers, from 1900 to 0700 two days later: one evening and one night for adaptation to the environment and adjustment of gas concentrations followed by 24 h of measurements. Before entering the chambers, they were fitted with probes for continuous recording of heart rate (HR) by telemetry (Life Scope 6, Nihon Kohden, Japan). During the 24 h measurement period subjects followed a definite activity program: they awoke at 0700, BMR was measured from 0700 to 0800 and they got up at 0800. They underwent four 15 min periods of exercises (at 0930, 1100, 1500, and 1730) at four intensities (40, 50, 30 and 60 % peak VO_2, respectively) on a cycle ergometer (Ergomega, Sorem, Toulon, France) at a pedalling rate of 70 rpm. Between the exercise sessions, subjects recorded only seated activities (schoolwork, reading, parlour games, video games, and watching TV). Volunteers were offered breakfast at 800, lunch at 1300, a snack at 1600, and dinner at 1930. The diet composition was fairly standardised but food intake was not determined. They went to bed at 2200. Supervision was continuous while subjects were in the calorimetric chambers.

Air flow, oxygen, and carbon dioxide concentration of air entering and leaving the chambers, as well as ambient temperature, relative humidity, and atmospheric pressure were recorded every minute (13). The accuracy for gas exchange measurements was determined gravimetrically by continuous injection of carbon dioxide and nitrogen into the chamber. The recovery was 99.5 ± 0.6 % for periods of 6–8 h, and 97.2 ± 1.6 % for periods of 15 min, simulating variations of physical activity (14). EE was calculated from O_2 consumption, CO_2 production, and 24 h urinary nitrogen excretion using Brouwer's equation (15) over periods of 5 min during exercises and 15 min for the rest of the day. EE was then pooled into six main periods: actual sleep (from 2300 to 0700), BMR (from 0700 to 0800), meals (lunch and dinner, 2 h including two 30 to 45 min periods of eating plus two 15 to 30 min postprandial periods of resting), rest (10 h, composed of seated activities: schoolwork, video games, parlour games, TV, etc.), cycling exercises plus recovery periods (30 min x 4), and miscellaneous activities (1 h) including breakfast, washing and dressing.

Statistical analysis

Values are expressed as least square (LS) means ± SDs. Data were analysed by using SAS Software (16). Two or three way analyses of variance were performed using the general linear model (GLM) procedure. Adjusted means (LS means) were compared by paired t test. Results obtained with boys who remained at Tanner's stage 1 and those who passed from stage 1 to stage 2 or 3 were compared using the non-parametric test of Wilcoxon (NPAR1WAY procedure) (16). Stepwise multiple regression on the whole set of data was used to determine the significant predictors of EE. Single and multiple-linear regression analyses were performed by using the GLM procedure.

Results

Changes in pubertal and anthropometric characteristics of subjects

Age and anthropometric characteristics of subjects at 10.4 and 12.8 years of age are shown in Table 1. The time interval between the two measurements was similar for boys and girls (2.37 ± 0.22 y). The sexual maturity of all the prepubertal children corresponded to Tanner's stage 1. However, at 12.8 years of age boys were between stages 1 and 3, and girls between stages 3 and 5, except one girl at stage

Table 1 Physical characteristics of subjects (LS means and SD of LS means)

	Boys		Girls		P value		
Stage of puberty	Prepubertal	Pubertal	Prepubertal	Pubertal	Age	Sex	A x S
Number of subjects	8	8	8	8			
Age (years)	10.49 ± 0.39	12.80 ± 0.32*	10.33 ± 0.44	12.76 ± 0.42*			
Tanner stage	1.0	2.1 ± 0.8*	1.0	3.5 ± 1.5*+	0.0001	0.03	0.03
Height (cm)	139.4 ± 5.2	153.4 ± 8.9	136.4 ± 6.0	153.7 ± 8.4*	0.0001	NS	NS
Weight (kg)	32.6 ± 5.6	43.8 ± 9.2	30.2 ± 3.3	43.9 ± 6.4*	0.0001	NS	NS
BMI ($kg.m^{-2}$)	16.7 ± 1.8	18.4 ± 2.4*	16.2 ± 1.4	18.5 ± 1.3*	0.003	NS	NS
FFM (kg)	25.0 ± 3.3	35.7 ± 7.1*	23.2 ± 1.9	34.5 ± 4.6*	0.0001	NS	NS
FM (kg)	7.5 ± 2.9	8.1 ± 2.8	6.9 ± 2.3	9.3 ± 2.7*	NS	NS	NS
% FM	22.5 ± 5.8	18.1 ± 3.5*	22.6 ± 4.9	21.2 ± 4.3	NS	NS	NS
TS (mm)	11.1 ± 3.3	9.1 ± 3.3*	10.7 ± 3.4	10.2 ± 2.2	NS	NS	NS
AC (cm)	20.3 ± 2.3	22.1 ± 2.7*	19.4 ± 1.8	21.9 ± 1.4*	0.006	NS	NS
TUA (cm^2)	33.0 ±7.3	39.3 ± 9.8*	30.1 ± 5.8	38.3 ± 4.8*	0.008	NS	NS
UFE (cm^2)	11.6 ± 4.6	10.3 ± 5.2	10.6 ± 4.5	11.3 ± 2.7	NS	NS	NS
UME (cm^2)	21.4 ± 3.0	29.0 ± 5.5*	19.5 ± 2.6	27.1 ± 3.9*	0.0001	NS	NS
Arm fat (%)	33.8 ± 6.9	25.3 ± 6.3*	34.3 ± 8.3	29.4 ± 6.0	0.01	NS	NS
Peak VO_2 ($L.min^{-1}$)	1.52 ± 0.18	2.00 ± 0.33*	1.40 ± 0.13	1.85 ± 0.20*	0.0001	0.09	NS
EMP (Watt)	89.7 ± 11.2	159.6 ± 22.3*	83.1 ± 12.4	136.0 ± 16.3*	0.0001	0.01	NS
Values adjusted for differences in FFM							
Adjusted Peak VO_2 ($l.min^{-1}$)	1.68 ± 0.06	1.79 ± 0.07	1.62 ± 0.07	1.68 ± 0.06	NS	NS	NS
Adjusted EMP (Watt)	102.1 ± 4.1	143.1 ± 4.5*	100.3 ± 4.5	122.8 ± 4.2*	0.0001	0.006	0.02

BMI body mass index, *FFM* fat-free mass, *FM* fat mass, *TS* triceps skinfold thickness, *AC* arm circumference, *TUA* total upper arm area, *UFE* upper arm fat area, *UME* upper arm muscle area, *Peak VO_2* maximal oxygen uptake, *EMP* external mechanical power corresponding to Peak VO_2. Peak VO_2 and EMP were adjusted for differences in FFM; +: one girl at Tanner's stage 1 and one girl at stage 2.
* significantly different from prepubertal children.

1 and one girl at stage 2, which agreed with the usual time lag in puberty between boys and girls. During the 2.4-y period, height gain, BW gain, and variations in body mass index (BMI) were not significantly different between boys and girls.

Changes in body composition

Body composition varied significantly during the 2.4-y period (Table 1). Mean yearly FFM gain was similar in boys and girls. However, it was 2.43 ± 0.21 kg in children who remained at Tanner's stage 1, and 5.22 ± 1.41 kg in those moving up from Tanner's stage 1 to Tanner's stage 2, 3, 4 or 5 (P< 0.02). Mean yearly FM gain was significant in girls (1.0 + 1.2 kg, $P < 0.05$), but not significant in boys (0.20 ± 0.66 kg). Consequently, the percentage of FM decreased by 4.4 units in boys ($P < 0.03$), whereas it did not vary significantly in girls during the 2.4-y period.

The total upper arm area (TUA) also increased significantly ($P < 0.008$) and similarly in boys and girls. Upper arm fat area (UFE) did not vary significantly in either gender, whereas upper arm muscle + bone area (UME) increased significantly ($P < 0.0001$) and similarly in boys and girls. Finally, the FM content in the upper arm decreased significantly ($P < 0.001$) in boys by 8.5 ± 4.5 percent units, but not significantly in girls over the 2.4-y period.

Changes in physical capacities

The children had a sedentary or moderately active lifestyle. They performed 3 to 7 hours school sport or training per week. There were no significant differences between groups but great variations in each group. Peak VO_2 increased significantly in boys and girls ($P < 0.002$). However, the increase was significantly greater in boys than in girls ($P < 0.03$). Furthermore, it was greater in boys who passed from Tanner's stage 1 to Tanner's stage 2 or 3 than in those who remained at Tanner's stage 1 (0.734 ± 0.112 $L.min^{-1}$ versus 0.286 ± 0.122 $L.min^{-1}$, P< 0.04), but not in girls. However, after adjustment for differences in FFM, there were no significant effects of age or gender on peak VO_2.

The external mechanical power (EMP) at peak VO_2 also increased significantly ($P < 0.0001$) between the ages of 10.4 and 12.8 years, but the increase was significantly greater in boys than in girls ($P < 0.0001$). Furthermore, EMP increased by 35.5 ± 4.6 $W.y^{-1}$ in boys who passed from Tanner's stage 1 to Tanner's stage 2 or 3, and 22.9 ± 1.85 $W.y^{-1}$ in boys who remained at Tanner's stage 1 (P< 0.05). On the contrary, there was only a small increase with Tanner's stage in girls. Finally, EMP adjusted for differences in FFM was similar in boys and girls at 10.4 years of age, but 20 W higher in boys than in girls at 12.8 years of age ($P < 0.0002$).

Changes in energy expenditure

Daily EE (DEE) and its main components measured under the same conditions at 10.4 and 12.8 years of age and with the same activity programme are presented in Table 2. DEE was similar in boys and girls at 10.4 years of age. It in-

Table 2 Energy expenditure as measured by whole-body indirect calorimetry (LS means and SD of LS means)

	Boys		Girls		P value		
Stage of puberty	Prepubertal	Pubertal	Prepubertal	Pubertal	Age	Sex	A x S
Number of subjects	8	8	8	8			
DEE (MJ)	7.16 ± 0.76	9.90 ± 1.33*	7.18 ± 0.65	9.59 ± 1.06*	0.01	NS	NS
SEE ($kJ.min^{-1}$)	3.33 ± 0.28	4.58 ± 0.51*	3.20 ± 0.28	4.20 ± 0.40*	0.001	NS	NS
EE Meals ($kJ.min^{-1}$)	6.09 ± 0.88	7.30 ± 1.13*	5.90 ± 0.90	7.43 ± 0.77*	NS	NS	NS
EE Miscellaneous ($kJ.min^{-1}$)	6.07 ± 0.86	7.15 ± 1.17*	6.18 ± 0.47	7.16 ± 0.96*	NS	NS	NS
REE ($kJ.min^{-1}$)	4.91 ± 0.63	7.06 ± 1.17*	5.10 ± 0.53	7.05 ± 0.89*	0.02	NS	NS
EE Exercise ($kJ.min^{-1}$)	10.44 ± 0.89	15.25 ± 1.93	10.32 ± 1.13	14.20 ± 1.62*	0.001	NS	NS
EE adjusted for differences in FFM							
DEE (MJ)	7.96 ± 0.25	8.82 ± 0.28*	8.28 ± 0.28	8.76 ± 0.25	0.08	NS	NS
SEE ($kJ.min^{-1}$)	3.64 ± 0.09	4.15 ± 0.10*	3.64 ± 0.10	3.87 ± 0.09	0.009	0.03	0.10
EE Meals ($kJ.min^{-1}$)	6.73 ± 0.28	6.44 ± 0.31	6.79 ± 0.31	6.77 ± 0.28	NS	NS	NS
EE Miscellaneous ($kJ.min^{-1}$)	6.65 ± 0.28	6.35 ± 0.31	6.99 ± 0.31	6.55 ± 0.29	NS	NS	NS
REE ($kJ.min^{-1}$)	5.53 ± 0.24	6.24 ± 0.26	5.94 ± 0.27	6.41 ± 0.24	NS	NS	NS
EE Exercise ($kJ.min^{-1}$)	11.57 ± 0.39	13.73 ± 0.42*	11.89 ± 0.43	13.03 ± 0.39	0.006	NS	NS

EE energy expenditure, *DEE* daily energy expenditure, *SEE* sleeping energy expenditure, *REE* resting energy expenditure
* significantly different from prepubertal children

creased significantly between 10.4 and 12.8 years of age by 2.74 ± 1.07 and 2.41 ± 0.82 MJ in boys and girls, respectively, but the gender difference was not significant. However, the increase in DEE tended to be lower in boys who remained at Tanner's stage 1 than in those who passed from Tanner's stage 1 to Tanner's stage 2 or 3 (1.68 + 0.26 vs 3.09 + 0.98 MJ, P = 0.10). By contrast, the increase in DEE did not vary significantly with Tanner's stage in girls. FFM was the major significant determinant of EE. Therefore, DEE was adjusted for differences in FFM for group comparisons. Adjusted DEE of boys was 11 % higher at 12.8 than at 10.4 years of age ($P < 0.05$). However, the effect of age was not significant in girls.

Sleeping EE (SEE) is expected to be the most representative criterion of changes in metabolic rate of the whole body with age. It was similar in boys and girls at 10.4 years of age and not significantly higher in boys than in girls at 12.8 years of age. Nevertheless, SEE increased significantly by 37.5 % and 31.2 % in boys and girls, respectively ($P < 0.0001$). Interestingly, the increase averaged 31 % in boys who remained at Tanner's stage 1, and 41 % in those who passed from Tanner's stage 1 to Tanner's stage 2 or 3 ($P < 0.03$). SEE adjusted for differences in FFM increased by 14 % ($P < 0.003$) in boys, but not significantly in girls between 10.4 and 12.8 years of age. It was also 7.2 % higher in boys than in girls at 12.8 years of age ($P < 0.03$).

Measurements of basal metabolic rate (BMR) of children at 10.4 years of age were not reliable because they did not remain quiet in bed during the measurement period. Therefore, the corresponding values of EE were included in the resting period for the four groups of children. Resting EE (REE) as measured over an eleven-hour period was not significantly different between boys and girls at 10.4 and 12.8 years of age. REE adjusted for differences in FFM tended to increase in boys and girls, but the differences were not significant. In other respects, adjusted EEs during meals and miscellaneous activities were not significantly different whatever gender or age.

Mean EEs adjusted for differences in FFM during the four 30 minute sessions were increased by 46 % and 38 % ($P < 0.0001$) in boys and girls, respectively, between 10.4 and 12.8 years of age. Nevertheless, adjusted EE, as well as the net exercise EEs, i. e. exercise EEs at steady state (6^{th} to 15^{th} min) minus SEEs, adjusted for differences in FFM and EMP, were not significantly different between boys and girls at 10.4 and 12.8 years of age.

Significant determinants of DEE and SEE

Stepwise-regression analyses were performed to determine the significant determinants of DEE and SEE. The following variables were used: sex, age, Tanner stage, FFM, FM, and peak VO_2. The significant determinants of the DEE were FFM ($r^2 = 0.866$, $P < 0.0001$), peak VO_2 ($r^2 = 0.017$, $P < 0.04$), and age ($r^2 = 0.014$, $P < 0.05$). SEE was best explained by FFM ($r^2 = 0.859$, $p < 0.0001$), age ($r^2 = 0.031$, $P < 0.006$), and Tanner stage ($r^2 = 0.025$, $P < 0.006$).

Discussion

This longitudinal study enabled direct evaluation of changes in body composition, physical capacities, and energy expenditure in boys and girls going into puberty. Children were studied at 10.4 years of age and 2.4 years later under the same conditions, with the same methods and equipment, and according to the same activity programme. Thus, the changes observed in these children could be directly linked to adolescent growth. However, girls reached puberty earlier than boys as expected (17), so that boys and girls could be compared at the same chronological ages, but not at the same puberty stages.

The results of this longitudinal study showed clear gender differences in body weight gain composition, and in increases in physical capacities and energy expenditure between 10.4 and 12.8 years of age, on the one hand, and differences related to Tanner's stage in boys at the onset of puberty, on the other hand. This suggests that, at an early stage of puberty, sex hormones differences may play an important role for changes in physical capacities and energy expenditure.

In spite of similar FFM gains in both genders, the percentage of FM decreased in boys as a result of a non-significant FM gain, whereas it was not significantly altered in girls, in agreement with the results of Roemmich et al. (2). As a matter of fact, in the present study, BW gain consisted of 95 % and 85 % FFM in boys and girls, respectively, which could explain that muscle mass increases from about 42 % to 54 % of BW in boys and from 40 % to 45 % in girls during the period of puberty (1). Indeed, increases in secretion of gonadotrophin, LH, FSH, testosterone as well as GH, IGF–1 and insulin in early puberty (2–4, 6–8) promote protein accretion (18, 19). The external mechanical power at peak VO_2 was similar in prepubertal children, but significantly higher in boys than in girls at 12.8 years of age, even after adjustment for FFM and peak VO_2. The difference did not seem to result from a greater muscle mass in boys, since FFM and upper arm muscle + bone area were not significantly different between boys and girls; therefore it might originate from gender differences in histological and metabolic muscle characteristics as in adults (28).

Daily and sleeping energy expenditures measured under standardised conditions increased by 38 and 32 % on average in boys and girls, respectively, during the 2.4-year period. Furthermore, DEE increased by 44 % in boys who passed from Tanner's stage 1 to Tanner's stage 2 or 3, compared to 29 % in boys who remained at Tanner's stage 1. These results stress the variations in energy requirements of children, especially boys, already at an early stage of puberty. Increases in EE in girls could be explained mainly by differences in body composition since sleeping, resting and

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daily EEs adjusted for differences in FFM were not significantly higher at 12.8 than at 10.4 years of age. However, adjusted DEE and SEE were 11 and 14% higher in 12.8- than in 10.4-y-old boys. This phenomenon may result from 1) increases in hormone secretion (LH, testosterone, GH, IGF-I) at the onset of puberty (2, 4–6, 8), 2) the effect of GH and thyroid hormones (2, 20) as well as testosterone on protein turnover and EE (18, 19, 21, 22) and 3) differences in tissue metabolic activity. GH, indeed, is thought to increase BMR through increasing the conversion of T4 to the more metabolically active T3 (20), increasing IGF-I secretion, which may participate in increasing resting EE (23), and induction of catecholamine release (24), which is known to be calorigenic.

In other respects, skeletal muscles were estimated to account for about 20% of whole-body oxygen uptake in adults (25). As the proportion of muscles in FFM increases during the pubertal growth (1), the contribution of skeletal muscles to basal, sleeping or resting EE increases by about 1% per year (26). Furthermore, 40 to 50% of the variability in BMR adjusted for differences in FFM, FM, age, and gender in adults was ascribed to the variability in skeletal muscle metabolic rate (27). The slightly higher proportion of type I fibre, the higher glycolytic potential of muscles (28), as well as the higher Na^+–K^+–ATPase activity of tissues in adult males than in females (29) may partly explain the higher adjusted EE of pubertal boys compared to that of pubertal girls.

Conclusion

In spite of the small number of subjects per group, this longitudinal study showed clear gender differences in body composition, resulting mainly from differences in fat mass gain, and physical capacities (peak VO_2 and adjusted external mechanical power at peak VO_2), as well as great increases in energy expenditure, especially in boys, at the onset of puberty. The latter could be explained mainly by variations in body composition in girls. However, the greater changes in EE and maximal aerobic power observed in boys may also result from variations in hormonal status and muscle tissue metabolic activity. These results stress the significant increase in energy requirements of children, especially boys, at an early stage of puberty.

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