BIOMEDICAL AND ENVIRONMENTAL SCIENCES **22**, 413-418 (2009) www.besjournal.com

Comparison of Changes in Body Composition during Puberty Development of Obese and Normal-weight Children in China[1]

JUN MA[#], NING FENG[+], SHI-WEI ZHANG[#], YONG-PING PAN[^], AND YONG-BO HUANG[&]

[#]Institute of Child and Adolescent Health, School of Public Health, Peking University, Beijing 100191, China; [+]National Center for Women and Children's Health, China CDC, Beijing 100013, China; [^]Institute of Primary and Secondary School Health of Dongcheng District, Beijing 100007, China; [&]Institute of Primary and Secondary School Health of Chongwen District, Beijing 100062, China

Objective To compare the changes in body composition, including fat mass index (FMI) and fat free mass index (FFMI) during puberty development of obese and normal-weight children in China, and to explore the effect of age and gender on body composition. **Methods** A total of 356 children at the age of 7-15 years were enrolled in this study. Body composition of 10 normal-weight and obese children in each age group was measured by dual-energy x-ray absorptiometry (DEXA). FFMI and FMI were calculated according to the following formula: FFMI ($kg \cdot m^{-2}$)= FFM(kg) / height^2 (m^2) and FMI ($kg \cdot m^{-2}$)= FM (kg) / height^2 (m^2). **Results** The fat mass and fat free mass of obese children were significantly higher than those of normal-weight children ($P<0.05$). The FMI and FFMI of obese children increased significantly with age and were higher than those of the same sex, gender, and age normal-weight children ($P<0.05$). **Conclusion** The levels of fat mass, fat free mass, FMI, and FFMI are different in obese and normal-weight children, and gender effects are significant in boys having higher levels of these indicators than in girls. FFMI and FMI can be used as monitoring indexes in weight control of obese children.

Key words: Puberty development; FMI; FFMI; Obese; DEXA

INTRODUCTION

With fast development in social economy and changes in life style, obesity has become one of the global major public health problems. According to the assessment criteria of WHO for obesity, the male with body fat percentage (BFP) >25% and the female with BFP>30% are regarded as obese[1]. The growth and development of children are fast during puberty and their body composition changes continuously[2-3]. The differences in body composition of males and females during pre-puberty and puberty are recognized[2, 4-6]. A child with a higher fat mass has a greater body mass index (BMI) and height[3]. The BMI of obese children, like normal-weight children, can be divided into fat-free mass index (FFMI) and fat mass index (FMI). The FFMI and FMI are calculated according to the following formula: FFMI ($kg\ m^{-2}$)=FFM (kg)/height^2 (m^2) and FMI ($kg\ m^{-2}$)=FM (kg)/height^2 (m^2). Up to date, few studies are available on the change of body composition, FFMI and FMI with age in Chinese obese children. The present study was to measure the FFM and FM of both normal-weight and obese children at the age of 7-15 years to understand the changes of FFMI and FMI with age in obese children, and their differences with those of normal-weight children. The study will provide the basic data for further weight control of obese children in China.

SUBJECTS AND METHODS

Subjects

Both normal-weight and obese children at the age of 7-15 years were selected from a primary school and a secondary school in Beijing, according to their heights and weights measured in National Primary and Secondary School Student Physique and Health Survey 2005. Informed consent was obtained

[1]This research was supported by the 973 Project "Mechanism of Type 2 Diabetes Progression" (No. 2006CB503900) from Ministry of Science and Technology of China and Scientific Program from General Administration of Sport of China (No. 06134).

Biographical note of the first author: Jun MA, male, born in 1961, professor, doctoral degree from School of Public Health, Peking University, majoring in child and adolescent health, with research focus on child growth & development and relevant factors.

0895-3988/2009
CN 11-2816/Q

from the participants prior to data collection. A total of 356 students were enrolled in this study. Of them, 176 were obese students who were assessed based on the BMI reference norm for screening overweight and obesity in Chinese children and adolescents by the Working Group on Obesity in Chinese (WGOC)[7], 180 were regarded as normal-weight students whose BMI was between the 25th and 75th percentiles according to the BMI reference criteria for a representative Chinese population in 2005[8].

Students were excluded from the study if they suffered from one of the following diseases such as cardiac disease, hypertension, pulmonary tuberculosis, asthma, hepatitis and nephritis, or abnormalities in development such as dwarfism and gigantism, or deformities such as severe scoliolosis, pigeon chest, gammy, O-shape and X-shape legs, or obesity due to endocrine diseases or drug side-effects.

Measurement

Body composition including the whole body and partial FM and FFM was measured by dual energy X-ray absorptiometry (DEXA; GE Medical System, Lunar Prodigy DF＋14492, USA) using the standard scan model with 0.4 μGy X-ray and 0.15 ampere electric current. The subjects were not allowed to consume any drugs or healthcare products two days before the measurement and wore only 100% cotton underwear during the measurement.

Statistical Analysis

Data were analyzed using SPSS 11.5 software according to the following formula: Fat-free mass index (FFMI) (kg m^{-2})＝FFM (kg)/height^2 (m^2), Fat mass index (FMI) (kg m^{-2})＝FM (kg)/height^2 (m^2). All related indices of body composition were expressed as $\bar{x} \pm s$. Difference between obese and normal-weight children was analyzed with *t*-test. P <0.05 was considered statistically significant.

RESULTS

Body Composition

The FM and BFP of normal-weight children increased with age from 7 to 13 years and then decreased slightly, while the FFM increased with age from 7 to 15 years (Tables 1 and 2). For each age group, the BFP of girls was higher than that of boys. The FM, BFP, and FFM of obese children were higher than those of the same sex and age normal-weight children. The differences were all statistically significant (P<0.05) but not in children at the age of 12 years.

TABLE 1

Body Composition of Normal-Weight and Obese Boys at the Age of 7-15 Years ($\bar{x} \pm s$)

Age (Year)	Normal-Weight (*n*=88)					Obese (*n*=90)				
	Case No.	BMI (kg m^{-2})	FM (kg)	FFM (kg)	BFP (%)	Case No.	BMI (kg m^{-2})	FM (kg)	FFM (kg)	BFP (%)
7	9	15.0±0.7	3.1 ±0.4	20.2±2.1	13.4 ±2.0	12	23.4±2.1	15.5±2.9	25.8±3.0*	37.2±3.0
8	8	15.5±1.0	5.2 ±1.6	21.6±1.6	19.1±5.1	12	22.4±1.7	15.2±4.1	26.8±2.3*	36.9±5.1
9	9	16.0±1.3	5.0±2.7	23.9±1.5	16.8±7.4	10	24.5±2.6	19.6±5.3	30.5±4.8*	38.7±3.7
10	9	16.4±1.4	6.4±2.9	27.6±3.1	18.5±6.4	7	24.5±2.7	20.9±4.6	32.9±4.8*	38.6±6.0
11	10	16.8±1.5	6.1±2.6	28.4±3.3	18.1±5.7	10	25.5±3.6	22.5±7.0	36.8±5.7*	37.4±5.0
12	12	17.6±1.0	7.7±3.1	35.1±6.0	18.3±7.5	12	26.1±2.1	26.1±5.8	38.3±5.5	40.3±6.1
13	8	19.0±1.8	8.4±3.2	41.2±8.1	15.8±5.1	8	27.9±4.5	25.8±9.6	50.8±8.6*	33.0±8.2
14	14	20.1±1.7	8.5±2.9	48.7±7.1	15.3±4.1	10	28.7±3.0	28.6±7.1	52.1±4.8*	34.1±4.6
15	9	20.0±0.9	6.1±1.9	51.0±5.9	10.7±3.2	9	30.3±5.0	31.1±11.2	59.5±8.2*	33.4±7.1

Note. *P<0.05 *vs* the same age normal-weight boys.

TABLE 2

Body Composition of Normal-Weight and Obese Girls at the Age of 7-15 Years ($\bar{x} \pm s$)

Age (Year)	Normal-Weight (n=92)					Obese (n=86)				
	Case No.	BMI (kg m^{-2})	FM (kg)	FFM (kg)	WBFP (%)	Case No.	BMI (kg m^{-2})	FM (kg)	FFM (kg)	WBFP (%)
7	12	14.9±1.1	3.8±1.0	17.4±1.6	17.8±3.4	9	19.6±2.5	11.2±4.2	22.2±2.1*	32.6±5.8
8	11	16.0±0.8	6.2±1.9	21.5±1.9	22.0±5.5	9	25.7±4.5	20.5±7.8	28.0±5.2*	41.0±6.3
9	9	16.3±1.3	7.2±2.6	22.2±3.4	23.9±4.7	11	23.6±3.4	19.1±6.0	28.8±3.7*	39.1±4.8
10	10	16.6±2.0	8.4±3.3	26.4±4.3	23.9±5.0	8	22.6±1.4	17.8±2.7	33.5±4.9*	34.7±2.0
11	10	17.9±1.3	9.9±2.3	31.1±4.4	23.6±4.9	10	25.0±1.6	22.9±4.0	37.2±1.9*	37.9±4.4
12	11	18.0±1.8	11.0±3.0	32.3±3.1	25.1±4.1	10	25.3±1.8	24.2±3.2	38.2±3.5*	38.7±2.9
13	9	19.8±1.3	15.4±2.9	36.8±3.2	29.3±4.4	10	26.9±3.2	27.5±8.5	42.0±5.0*	38.9±6.4
14	11	19.4±1.3	13.6±3.4	36.2±2.7	27.0±4.9	10	28.5±4.3	30.1±7.7	41.1±2.3*	41.6±6.4
15	9	19.7±1.7	13.4±3.4	37.5±3.7	26.1±4.8	9	19.6±2.5	11.2±4.2	22.2±2.1*	32.6±5.8

Note. *P<0.05 *vs* the same age normal-weight girls.

FFMI and FMI

The mean FFMI (kg m^{-2}) of normal-weight boys at the age of 7-15 years increased with age from 12.44 to 17.89, while the FMI (kg m^{-2}) increased from 1.99 to 3.21 at the age of 12 years and then decreased to 2.14 at the age of 15 years. The increment of FMI was fast at the age of 7-8 years. The mean FFMI of normal-weight girls at the age of 7-15 years also increased with age from 11.68 to 14.28, while the FMI (kg m^{-2}) increased from 2.54 to 5.75 at the age of 12 years and then decreased to 5.12 at the age of 15 years. The increment of FMI was fast at the ages of 7-8 and 12-13 years.

The FFMI of boys was higher than that of the same age girls and the difference in different age groups (7, 9, 14, and 15 years) was statistically significant (P<0.05). The FFMI of boys increased from 7 to 15 years, which was as about twice as that of girls. The FMI of boys was lower than that of the same age girls and the difference in different age groups (7, 11-15 years) was statistically significant (P<0.05). The FFMI of girls increased from 7 to 15 years, which was as about twice as that of boys (Table 3).

TABLE 3

Height (cm), FFMI (kg m^{-2}), and FMI (kg m^{-2}) of Normal-Weight Children at the Age of 7-15 Years ($\bar{x} \pm s$)

Age	Boys (n=88)			Girls (n=92)		
(Year)	Height (cm)	FFMI (kg m^{-2})	FMI (kg m^{-2})	Height (cm)	FFMI (kg m^{-2})	FMI (kg m^{-2})
7	125.20±5.13	12.86±0.61*	1.99±0.29*	122.12±3.02	11.68±0.81	2.54±0.61
8	131.89±5.64	12.44±0.69	2.97±0.89	133.08±4.67	12.13±0.65	3.46±0.96
9	134.92±4.40	13.15±0.90*	2.73±1.39	134.83±8.17	12.14±0.80	3.88±1.07
10	144.33±5.01	13.23±0.99	3.06±1.27	143.86±7.28	12.68±0.94	3.93±1.24
11	143.25±6.67*	13.78±0.76	2.97±1.19*	154.51±5.71	13.01±1.49	4.19±1.06
12	156.66±6.80	14.20±1.30	3.21±1.39*	155.41±4.92	13.34±0.89	4.52±1.11
13	166.60±3.50	14.81±2.70	3.00±1.16*	163.49±4.36	13.76±0.69	5.75±1.13
14	169.42±7.11*	16.88±1.64*	2.98±1.02*	161.77±4.54	13.81±0.65	5.14±1.16
15	168.63±6.91*	17.89±0.87*	2.14±0.66*	161.87±6.51	14.28±0.74	5.12±1.31

Note. *P<0.05 *vs* girls.

The FFMI (kg m^{-2}) of obese children increased with age at the age of 7-15 years. The mean FFMI of boys and girls was 14.0-20.0 (kg m^{-2}) and 12.5-16.5 (kg m^{-2}), respectively. Its increment was similar in obese and normal-weight children, which was about 5.0 (kg m^{-2}) of boys and 2.5 (kg m^{-2}) of girls. The FFMI of obese children was 1.5-2.0 (kg m^{-2}) and 1.0-2.5 (kg m^{-2}), higher than that of the same sex and age normal-weight boys and girls (P<0.05). The increment of FMI was less than that of FFMI in obese children, fluctuating between 8 and 11 (kg m^{-2}), 6 and 12 (kg m^{-2}) in boys and girls, respectively (Table 4).

TABLE 4

Height (cm), FFMI (kg m^{-2}), and FMI (kg m^{-2}) of Obese Children at the Age of 7-15 Years Old ($\bar{x} \pm s$)

Age (Year)	Boys (n=90)			Girls (n=86)		
	Height (m)	FFMI (kg m^{-2})	FMI (kg m^{-2})	Height (m)	FFMI (kg m^{-2})	FMI (kg m^{-2})
7	133.68±4.42*	14.46±1.27*	8.64±1.36*	131.01±4.18*	12.96±0.68*	6.45±2.03*
8	137.42±5.63*	14.23±1.11*	8.03±1.88*	136.94±6.39	14.85±1.71*	10.68±3.24*
9	143.13±6.78*	14.81±1.06*	9.48±1.83*	143.07±6.04*	14.06±1.14*	9.26±2.54*
10	149.86±6.12	14.62±1.45*	9.35±2.17*	150.51±8.47	14.74±1.00*	7.84±0.73*
11	152.55±5.23*	15.80±1.70*	9.62±2.54*	156.60±3.24	15.22±0.95*	9.35±1.56*
12	157.54±7.16	15.37±1.20*	10.52±2.25*	157.70±5.14	15.34±0.79*	9.75±1.24*
13	165.75±6.56	18.39±2.12*	9.38±3.29*	161.38±5.36	16.12±1.51*	10.48±2.81*
14	168.58±5.85	18.37±1.84*	10.01±2.11*	159.73±5.58	16.16±1.04*	11.94±3.60*
15	173.56±5.61	19.73±2.04*	10.30±3.54*	161.53±3.02	15.96±1.14*	9.56±1.24*

Note. *P<0.05 *vs* normal-weight children.

To reveal graphically the body composition change with age as a quantitative measure, a body composition chart (Fig. 1) based on the FFMI and FMI was used in the study as previously described[5, 9]. The mean FFMI and FMI of boys and girls in each age group were plotted on the body composition chart with the x-axis representing the FFMI and the y-axis representing the FMI. Since the sum of FMI and FFMI was equal to the BMI, and the BFP was to the FMI/(FMI+FFMI), the BMI and BFP were added as diagonal lines in the chart showing the changes of FFMI, FMI, BMI, and BFP in both obese and normal-weight children at the age of 7-15 years. The BMI of obese children was 20.0-30.0 (kg m^{-2}). The BMI of boys was higher than that of girls. The BMI of normal-weight children ranged 13.0-20.0 (kg m^{-2}), the BFP of obese children and normal-weight children ranged 30%-45% and 10%-30%, respectively. The BFP of girls was higher than that of boys. The FFMI of normal-weight boys increased obviously with age, and fluctuated between 12.0 and 18.0 (kg m^{-2}). The FMI and FFMI of normal-weight girls changed little and fluctuated at a range of 2.0 and 3.5 (kg m^{-2}) and of 11.5 and 14.5 (kg m^{-2}), respectively. However, the fluctuating at a range of 2.5 and 6.0 (kg m^{-2}) increased obviously. The FFMI of obese children and normal-weight children had a similar change tendency. At the same time, the FMI of obese children was significantly higher than that of normal-weight children, demonstrating that the increased fat mass is the main component of the weight gain in obese children.

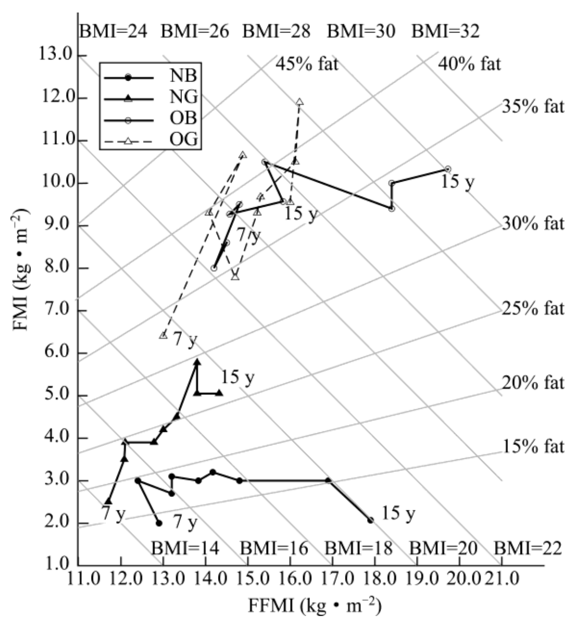

FIG. 1. Changes of FFMI and FMI in children at the age of 7-15 years in China.

DISCUSSION

Body composition refers to the ratio of an individual's percentage of fat mass to fat free mass (muscle, organs, *etc.*)[10]. During the growth and development of children, the content, proportion, and distribution of FM and FFM would change with age, especially at pre- and postadolescence. It has been found that the difference of FM and FFM in boys and girls is significant[2-4]. A number of studies have used body fat percentage (BFP) and FFM as an indicator of the FM and FFM content[11-12]. Body fat percentage calculated from FM and FFM is closely related to FFM. Increased or decreased BFP is synchronized with the fluctuation of FFM. Consequently, direct comparison of BFP with FFM among individuals has its limitations[13-14].

Furthermore, effects of height on the variance of FM and FFM are 2% and 45%, respectively[15]. When the changes of FM and FFM are compared, it is necessary to correct the height, especially the fast increasing height and weight of children. BMI, calculated from the correction of weight with height's square, can limit the effect of height on weight[7] and has become a worldwide index in evaluation of the growth and development of children and in screening of overweight and obesity. Although BMI is closely related with BFP, it cannot provide direct information on FM and FFM and may otherwise produce incorrect estimation of BFP. For example, BMI may overestimate the BFP of males and underestimate BFP of females[16]. In 1990, VanItallie *et al.*[15] first used height to correct FM and FFM in their research on adult body composition, and divided BMI into FM (kg)/height^2 (m^2) and FFM (kg)/height^2 (m^2), which was named as fat free mass index (FFMI) and fat mass index (FMI), respectively.

The present study demonstrated that both content and proportion of FM and FFM changed continuously during the growth and development of a child. The FM but not BFP of girls increased continuously. The FM of girls increased fast at the age of 7-9 years and 11-13 years, respectively, especially at the age of 12-13 years, which is consistent with the previous findings[17]. Although weight increased after the age of 13 years, BFP decreased obviously, demonstrating that FFM still increases after the age of 13 years.

The increased BMI of children at the age of 7-15 years may be due to the slowly increased FMI of boys, and the similarly increased FFMI and FMI of girls before the age of 13 years, or due to the decreased FMI and fast increased FFMI of boys at the age of 13-15 years. The tendency that FFMI of older boys increased faster than that of younger boys is consistent with the previously-reported data[18]. The decreased FMI of boys at the age of 14-15 years was accompanied by a fast elevated FFMI to maintain a steady level of BMI, while the increased steadily FFMI of girls was accompanied by a slightly decreased FMI. Generally, the mean BMI and its changing pattern of boys and girls are similar, while of the mean FFMI and FMI and their changing pattern are significantly different between boys and girls. The elevated BMI of boys was mainly caused by the increased FFMI, especially in puberty when the elevated BMI was caused by fast increased FFMI, while the elevated FFMI and FMI of girls would increase BMI. The changing pattern of FMI was more similar to that of BMI in puberty, indicating that FM and FFM play an important role in the change of BMI.

The height of children increases with their weight gain, which is different from that of adults. It was reported that children, especially boys, with a greater age-specific height have a higher BMI[19]. Forbes[20] showed that a higher BMI is not only caused by excess fat mass but also by height. Children with a higher BMI have a greater height. Hime and Roche reported[21] that the thicker the FM is, the greater the height of girls at the age of 9-14 years. Further study is needed to show the correlation between FFMI, FMI, BMI, and height.

The difference in BMI of obese and normal-weight children is due to the gaps between FFMI and FMI. That is, FFMI and FMI of obese children were higher than those of normal-weight children. The difference in FMI of obese and normal-weight children was more significant than that in FFMI. The difference in boys was greater than that in girls. The FFMI of obese children was significantly greater than that of normal-weight children. However, the increasing pattern of FFMI was similar in obese and normal-weight children. The FMI of obese boys was higher than that of normal-weight children. Their changing pattern was different. The change of FMI in obese girls was closely related with BMI.

This study used the body composition chart[9] to analyze the changes of FFMI and FMI and their effect on BMI. The FFMI, FMI, BMI, and BFP of obese children were higher than those of normal-weight children. The FFMI and FMI of children at different ages might cross several BMI values in the same BFP range (35%-40%), demonstrating that it is difficult for BMI to reflect BFP, although the correlation coefficient for BMI and FMI of obese children was higher than that of normal-weight children.

The increased BMI of obese children' was accompanied by the elevated FM and FMI. Consequently, weight control in obese children affects not only FM but also FFM. Weight loss includes not only FM loss, but also change of FFM.

Weight management in obese children should control the increase of FM, without affecting the growth of FFM. Furthermore, because the change of FFMI and BMI in boys and girls is similar, and the FMI of girls was sensitive to BMI change during puberty, the change of BMI in girls during weight control may be more likely to affect FMI and FM. Meanwhile, since the change of FM is more responsive to the weight change than that of FFM, weight control might be easier in girls than in boys. The correlation between FMI and FFMI of obese children at the age of 13-15 years was statistically significant. The effect of weight control might be different on adolescent boys and girls. Further study is needed to verify it because both nutrition and physical activity are also important environmental factors for weight control.

The correlation between height, FMI, and FFMI was not statistically significant in most obese children at the age of 7-15 years, demonstrating that height increases slower than FM and FFM when BMI is higher than the 95th percentile. Since FFMI and FMI increase with FFM and FM, respectively, it is difficult for obese children to change their high FFMI and to decrease their FMI to a normal range. Thus, in order to further control the weight of obese children, not only BMI change but also FFMI and FMI change should be used as monitoring indices. Since only 10 subjects were included in each age and gender group, further large-scale studies are needed to validate the difference in body composition change between obese and normal-weight children during puberty development and to investigate the actual change FFMI and FMI due to proper weight loss in obese children.

ACKNOWLEDGEMENTS

The authors thank Professor Shou-Qing LIN, Beijing Union Hospital for his technical support for DEXA measurement in the study.

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(*Received December* 10, 2008 *Accepted August* 25, 2009)