Original Article

Evaluation of partial body composition using bioelectrical impedance in Japanese children

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To clarify the growth pattern of body composition by body part for the management of childhood obesity, we measured body fat and muscle using BIA (bioelectrical impedance analysis) in 685 Japanese elementary school-children (aged 6-11 years). The growth patterns of percentage body fat (%BF), fat mass (FM), and muscle mass (MM) were examined throughout the whole body and in various body parts. The %BF of the whole body was greater in females than in males, and this difference widened with age. The %BF, FM, and MM in each body part showed similar growth patterns and gender differences to those of the whole body. The mean %BF of the left limbs was higher than that of the right limbs at all age groups. BMI was strongly correlated with %BF in both sexes. In conclusion, the compositions of all body parts change similarly with age, and gender differences are also similar in childhood. The effect of one's dominant arm on body composition is seen at a young age. The accumulation of body composition data according to body part is indispensable for understanding childhood body composition and managing obesity.

Key Words: bioelectrical impedance, partial body composition, fat, muscle, children

INTRODUCTION

Body mass index (BMI) is assumed to be an index of fat accumulation in children, although it is not ideal. International cut-off points for being overweight and obesity were published by Cole *et al*.[1] and we reported previously that these cut-off points could be used for Japanese children.[2] On the other hand, the percentage of overweight (POW) is used for the evaluation of childhood obesity in clinical practice in Japan.[3] Both BMI and POW are considered to reflect fat mass, but their predictive values for children and adolescents are less clear than for adults. However, the evaluation of fat mass and its distribution is very important for determining obesity.

Body composition has been evaluated using the bioelectrical impedance analysis (BIA) method, which can distinguish between lean and fat tissue on the basis of their different conductance and impedance characteristics.[4] Although BIA has been shown to be reliable and valid, even in children,[5-8] it incorporates various assumptions, and therefore, its accuracy in individuals remains poor, and measurements may be confounded by clinical status.[9] Consequently, we need more accurate data from healthy individuals in order to be able to evaluate morbidity. To avoid the confounding effect of variability in body build, segmental measurements of the limbs and torso are considered to be useful, but few reports have examined body composition according to body part in detail. Studying the growth patterns of body composition according to body part is indispensable for understanding the development of obesity and the changes in body composition induced by disease and medicine.

In this study, we examined age- and sex-specific body composition according to body part in Japanese healthy children using the BIA method.

MATERIALS AND METHODS

Subjects

The subjects were 685 healthy elementary school children (323 boys and 362 girls) who were aged 6-11 years. Their parents/guardians were sent a letter explaining the aims of the study and requesting permission for their child to take part. No subjects had significant chronic disease. No physically handicapped children or children on special diet treatments were included in the study population. Data on date of birth and gender were collected together with anthropometry. The children were individually coded, and the data were anonymized.

Anthropometric and body composition measurements

Measurements were conducted on the school premises by

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Manuscript received 11 May 2010. Initial review completed 6 July 2010. Revision accepted 11 August 2010.

Table 1. Baseline characteristics of the study population

	Male			Female		
age	number	BMI (kg/m2)	POW (%)	number	BMI (kg/m2)	POW (%)
6 y	65	15.1±1.2	-3.9±7.6	66	15.2±1.2	3.0±7.8
7 y	44	15.8±1.6	2.0±9.8	66	15.5±1.5	1.3±9.6
8 y	53	15.9±1.7	-1.3±1.1	60	15.9±2.0	1.2±1.2
9 y	55	16.7±1.9	2.2±1.1	58	16.4±2.4	8.2±1.4
10 y	47	17.2±2.6	9.6±1.4	48	17.4±2.6	9.2±1.4
11 y	59	17.7±2.8	5.0±1.5	64	17.8±2.6	-4.1±1.2

Results are expressed as mean±SD (range)

the nurse-teacher during the scheduled group check-up. All check-ups for the same school year were performed before lunch on the same day.

BMI and POW were calculated as body weight (kg)/ height^2(m^2) and 100×(measured weight－normal weight)/ standard normal weight (%), respectively (Table 1). Body composition was measured using the Tanita MC-190 body composition analyzer (Tanita Corp., Tokyo, Japan) with correction for light indoor clothing. The measurement procedure required the subject to stand barefooted on the analyzer and to hold a pair of handgrips, one in each hand. The device uses multiple-frequency (5 kHz, 50 kHz, 250 kHz, and 500 kHz) BIA technology, and has 8 tactile electrodes: 2 are in contact with the palm and thumb of each hand, and 2 are in contact with the anterior and posterior aspect of the sole of each foot.

To calculate the percentage body fat (%BF), fat mass (FM), and fat free mass for the whole body, the MC-190 uses data acquired using dual energy X-ray absorptiometry (DXA) from both Japanese and Western subjects as well as a regression formula derived through repeated regression analysis of height, weight, age, and impedance between the right hand and foot as variables. Measurements of %BF, FM, and predicted muscle mass (MM) for specific body parts using a regression formula for each body part derived from repeated regression analysis of height, weight, age, and impedance for individual body parts (right arm, left arm, right leg, left leg, and the trunk) as variables, based on data acquired through DXA.

In a sample of 79 boys (age 10±4.3 years) and 211 girls (age 11±4.7 years) in Japan, the impedance scales were highly correlated with those produced by DXA (DPX-IQ, Lunar Corporation, Madison, U.S.A.); (whole body %BF: r=0.92, SEE=3.03% in boys and r=0.95, SEE=2.76% in girls, whole body MM: r=0.99, SEE=1.25% in boys and r=0.99, SE=1.23 in girls). Pietrobelli, *et al.*[10] reported that the %BF of each part measured with the BC-418, which is also made by TANITA, strongly correlated with those measured with DXA, although no data for children were included. According to TANITA, the accuracy of the estimates of the composition of each body part produced by the MC-190 is equal to that of the estimates produced by the BC-418 because both use the same system. Taken together, we consider that this BIA device can accurately predict segmental body composition.

Ethical approval

This study was approved by the NHO Okayama Medical Center Ethics Committee.

Statistical analysis

Statistical analysis was performed using Dr. SPSSII for Windows (SPSS, Inc., Chicago, IL). The gender differences in mean values were examined using Student *t*-test. The differences among age groups were analyzed by ANOVA with Bonferroni's comparison. The laterality of mean values was analyzed using a paired *t*-test. Simple regression analysis was used to assess the correlation among %BF, FM, MM, BMI, and POW. A *p*-value of less than 0.05 was considered to indicate statistical significance.

RESULTS

Patterns of change in total %BF

Whole body %BF increased with age, increasing steeply after 7 years old in girls. While whole body %BF increased with age overall, it decreased slightly from 7 to 8 years and increased slightly from 9 to 11 years in boys. Whole body %BF was significantly higher in girls than in boys at all ages except at 7 years, and the difference increased with age. (Figure 1, Table 2)

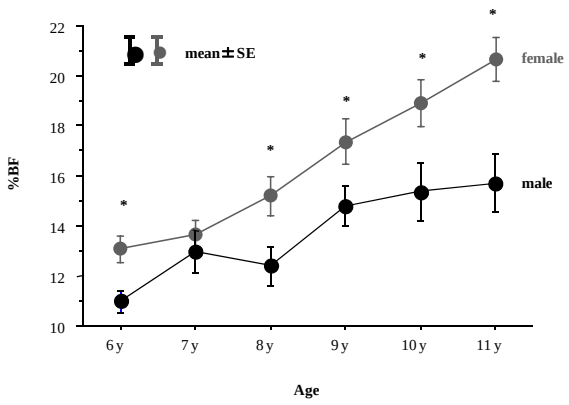

Figure 1. Total percentage body fat in relation to age. *p<0.05 (male vs. female)

Table 2. Significance probabilities among age groups

	Male					Female				
	7 y	8 y	9 y	10 y	11 y	7 y	8 y	9 y	10 y	11 y
%BF										
6 y	n.s.	n.s.	*	*	*	n.s.	n.s.	*	*	*
7 y		n.s.	n.s.	n.s.	n.s.		n.s.	*	*	*
8 y			n.s.	n.s.	n.s.			n.s.	*	*
9 y				n.s.	n.s.				n.s.	*
10 y					n.s					n.s
FF										
6 y	n.s.	n.s.	*	*	*	n.s.	n.s.	*	*	*
7 y		n.s.	n.s.	*	*		n.s.	*	*	*
8 y			n.s.	*	*			n.s.	*	*
9 y				n.s.	*				n.s.	*
10 y					n.s.					n.s.
MM										
6 y	*	*	*	*	*	*	*	*	*	*
7 y		*	*	*.	*		*	*	*	*
8 y			*	*	*			*	*	*
9 y				*	*				*	*
10 y					*					*

n.s. not significant *p< 0.05

Patterns of change in total FM

In girls, whole body FM increased with age, increasing steeply after 7 years old, as observed in %BF. In boys, whole body FM increased with age overall except at ages 7 to 8 years. Whole body FM was higher in girls than in boys at all ages except at 7 y, and the difference increased with age. (Figure 2, Table 2)

Patterns of change in total MM

Whole body MM increased with age, increasing steeply after age 9 y in boys. In girls, whole body MM increased with age, as observed in boys. Whole body MM was significantly larger in boys than in girls from age 6 to 9 y, but there were no significant difference for ages 10 to 11 y. (Figure 3, Table 2)

Patterns of change in partial %BF

Trunk, arm, and leg %BF showed a similar pattern of change to that of whole body %BF in both sexes. However, leg %BF did not increase after age 9 y in boys. The differences in each body part between boys and girls were also similar to those observed for the whole body. In Figure 4, patterns of change in right arm and right leg %BF are shown as representatives of limb %BF.

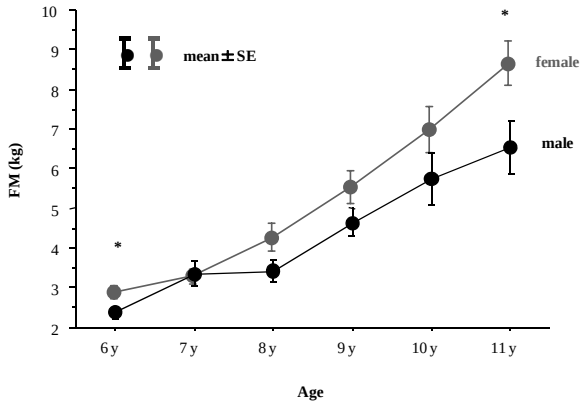

Figure 2. Total fat mass in relation to age. *p<0.05 (male vs. female)

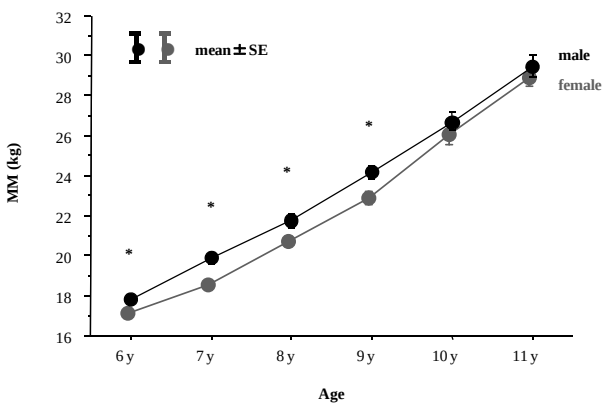

Figure 3. Total muscle mass in relation to age. *p<0.05 (male vs. female)

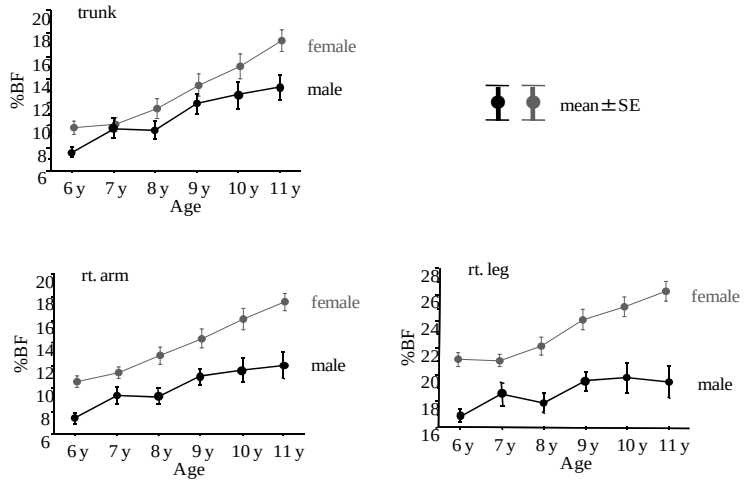

Figure 4. Partial percentage body fat in relation to age.

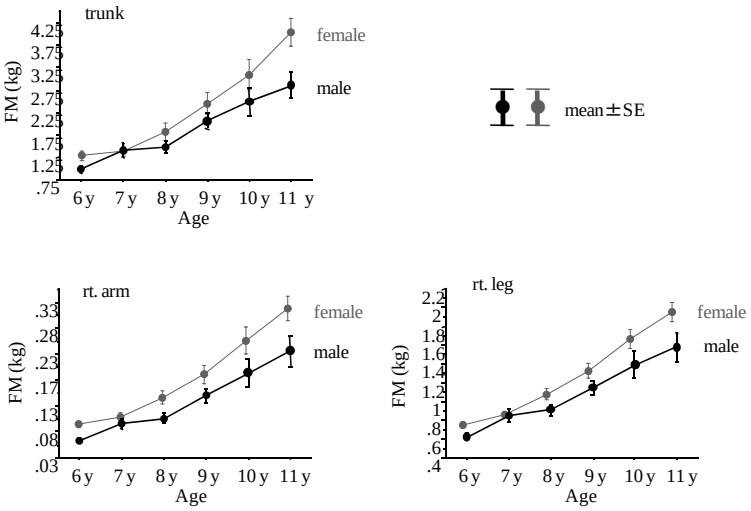

Figure 5. Partial fat mass in relation to age.

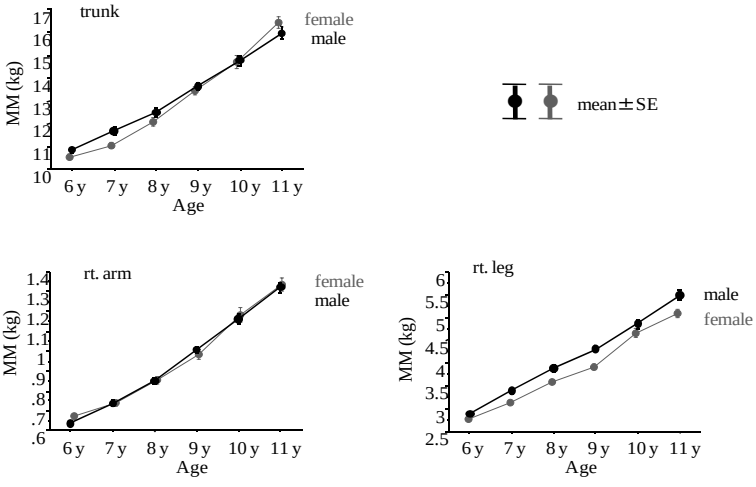

Figure 6. Partial muscle mass in relation to age.

Patterns of change in partial FM

Each partial FM showed a similar pattern of change to that of the whole body FM in both sexes. The differences in each part between boys and girls were also similar to those observed for the whole body. In Figure 5, the patterns of change in the right arm and right leg FM are shown as representatives of limb FM.

Patterns of change in partial MM

Each partial MM showed a similar pattern of change to that of the whole body MM in both sexes. The differences in each part between boys and girls were also similar to those observed for the whole body except at 11 years in the trunk and at 6 years in the arms. In Figure 6, the pat-

terns of change in right arm and right leg MM are shown as representatives of limb MM.

Asymmetry of limb %BF

Right arm %BF and left arm %BF showed similar growth patterns and so did right leg %BF and left leg %BF in both sexes. In both sexes, the left side %BF was higher than that for the right side at all ages, but there was a small difference as age increased. In particular, the difference between the right and left sides was marked in boys. (Figure 7)

Correlation among %BF, BMI, and POW

Both BMI and POW were highly correlated with %BF in both sexes. The correlation between BMI and %BF was stronger than that between POW and %BF in both sexes, and the correlations among %BF, BMI, and POW in boys were stronger than those in girls. (Figure 8)

DISCUSSION

BMI is widely used to assess whether individuals are overweight or obese. It is simple to measure and is a valuable tool for monitoring trends in obesity. POW is widely used in place of BMI in Japan and theoretically is the best method for following weight over time.[3] However, both methods have numerous disadvantages. Principally, they do not distinguish between increased mass in the form of fat, lean tissue, or bone. BIA is slightly less accurate than the more sophisticated research tools, but offers an important practical advantage in being simple and cheap to use.[11]

Although there have been several reports about whole body composition in children determined using BIA, to our knowledge no report have been made on body composition according to body part. Dai *et al*. reported that %BF decreased in males, increased with age in females, and was consistently greater in females than in males, with the sex difference widening with age for American children aged 8 to 18 y.[12] They also showed a difference in the growth pattern of body composition between blacks and non-blacks. Body fat reference curves have been reported for Caucasian children aged 5.0 to 18.5 years and

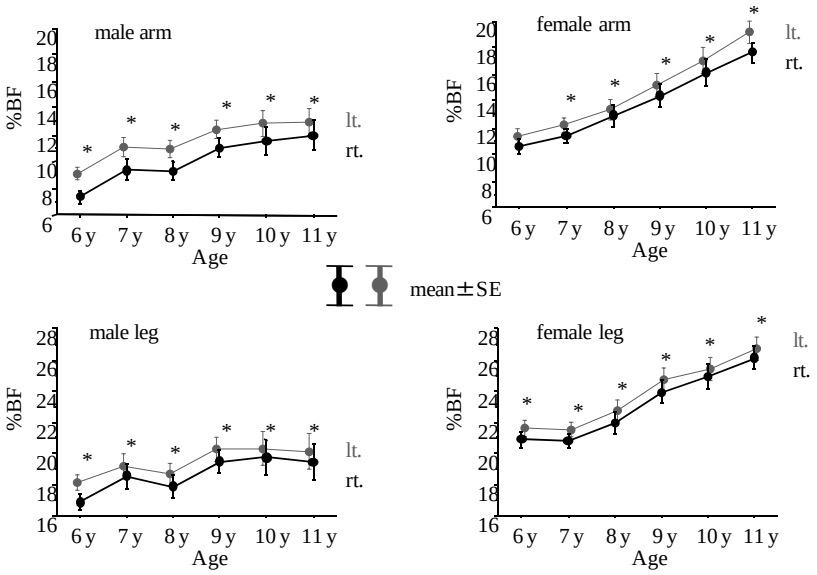

Figure 7. Asymmetry of limb percentage body fat. *p<0.05 (right vs. left)

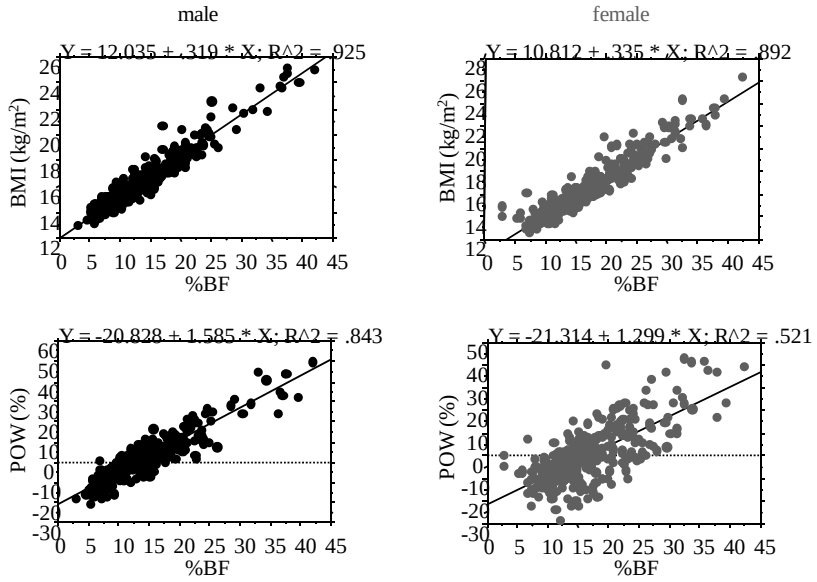

Figure 8. Correlations between body mass index, percentage of overweight, and percentage body fat.

showed that the curves for each sex were similar until puberty but then diverged markedly, with males proportionately decreasing in body fat and females continuing to gain.[11] For Chinese children aged 6 to 14 years, Li *et al*. showed that boys had a higher fat-free mass and a lower %BF than girls at all ages.[7] Although these previous reports examined age- and sex-specific whole body composition, neither body composition according to body part nor MM was examined. Therefore, this study is the first report concerning childhood body composition according to body part.

In this study, whole body %BF showed a similar growth pattern to previous reports; i.e., %BF was greater in females than in males, and this difference widened with age. By measuring FM and MM at the same time, we were able to demonstrate that one possible reason for this is that MM increases at the same rate in both sexes while FM increases at different speeds. In particular, it was proven that body fat percentage increases in girls during adolescence. Although Li *et al.* did not examine this matter, they reported similar data.[7] This gender gap in body composition in adolescents is thought to be dependent on differences in the influence of sex hormones and momentum. However, the cause of the gender gap in the younger children, in which the influence of sex hormones is small, remains uncertain.

The %BF, FM, and MM according to body part showed similar growth patterns and gender differences to those for the whole body. Therefore, for healthy children it is thought that overall body composition changes almost uniformly according to age. However, the leg %BF in males did not increase in the older children, unlike those for other parts. This might be related to the fact that growth momentum increases rapidly when boys are older and that sex hormones have site-specific effects on body composition. Although Fuller *et al*. reported the utility of segmental BIA in a small number of children,[13,14] this study is the first to examine body composition according to body part in relation to age and examine a larger number of children compared to previous studies.owever, the number of samples is still low. So, the accumulation of similar reports is necessary.

Although no laterality was seen in the growth pattern of %BF for the arm or leg in either sex, the mean %BF for the left side was higher than that for the right side at all ages. There was an age-dependent trend towards differences based on handedness, and right-handedness is far more abundant in Japan. It was reported previously that there were racial differences in the change in %BF according to age,[12] although laterality has not been reported before. Pietrobelli *et al*.[10] demonstrated good correlations between BC-418 and DXA measured regional %BF, but they did not demonstrate a significant difference between the right and left sides. Therefore, this laterality might be specific to the Japanese population, but similar investigations are required in other regions and races.

It is necessary to understand the changes in body composition that occur in healthy children with age in order to understand the development of obesity and the effects that sickness and medicine have on body composition. In addition, it is very useful to examine body composition according to body part in order to understand children's growth processes in detail and to understand the localization of the action of medicine. Therefore, the examination of more samples and different races is required in the future. BIA is a portable, noninvasive, safe, and attractive method for measuring body composition that is especially useful for large-scale population studies as compared to traditional, laboratory-bound, age-limited, and expensive methods.[15] Consequently, BIA may be more useful and valid in children than in adults, although this technique is slightly less accurate than more sophisticated research tools.[11]

BMI was strongly correlated with %BF in both sexes, as reported by Li *et al*.[7] POW also correlated with %BF, but the correlation was a little bit weaker than that for BMI, particularly in females. Therefore, BMI might be more useful than POW for examining fat distribution. POW is theoretically better for following weight over time than BMI. However, considering the fact that BMI seems to reflect fat distribution better than POW and that BMI is used in most countries for the evaluation of overweight, it will be necessary to use BMI in Japan in the future.

In summary, 1) the growth pattern of body composition is similar in all body parts, although uniqueness is seen according to body part when detailed examinations are performed in childhood. 2) the effect of one's dominant arm on body composition is seen at a young age. 3) Both BMI and POW are useful for evaluating body fat, but BMI is more useful for follow-up examinations.

In conclusion, 1) in future evaluations of body composition, it is necessary to take not only gender and age differences but also laterality into consideration. 2) The accumulation of body composition data according to body part is indispensable for understanding childhood body composition.

ACKNOWLEDGEMENTS

This work was supported by the National Hospital Organization of Japan.

AUTHOR DISCLOSURES

We declare no conflict of interest.

REFERENCES

1. Cole TJ, Bellozzi MC, Flegal KM, Dietz W. Establishing standard definition for child overweight and obesity worldwide: international survey. BMJ. 2000;320:1240-3.
2. Kubo T, Furujo M, Ueda Y, Imai K, Tsukahara K, Morita H et al. Predicting obesity in early adulthood in Japanese women. J Paediatr Child Health. 2008;44:33-7.
3. Asayama K, Ohzeki T, Sugihara S, Ohzeki T, Sugihara S, Ito K, et al. Criteria for medical intervention in obese children: a new definition of 'obesity disease' in Japanese children. Pediatr Int. 2003;45:642-6.
4. Chumlea WC, Guo S. Bioelectrical impedance and body composition: present status and future directions. Nutr Rev. 1994;52:123-31.
5. Iwata F, Hara M, Okada T, Harada K, Li S. Assessment of body composition measured by bioelectrical impedance in children. Acta Paediatr Jpn. 1993;35:369-72.
6. Tyrrell VJ, Richards G, Hofman P, Gillies GF, Robinson E, Cutfield WS. Foot-to-foot bioelectrical impedance analysis. A valuable tool for the measurement of body composition in children. Int J Obes. 2001;25:273-8.

7. Li S, Zhang M, Yang S, Okada T, Iwata F, Harada K. Age- and sex-specific body composition of Chinese children. Acta Paediatr. 2005;94:1139-42.
8. Prins M, Hawkesworth S, Wright A, Fulford AJC, Jarjou LMA, Prentice AM, Moore SE. Use of bioelectrical impedance analysis to assess body composition in rural Gambian children. Eur J Clin Nutr. 2008;62:1065-74.
9. Wells JCK, Fewtrell MS. Measuring body composition. Arch Dis Child. 2006;91:612-7.
10. Pietrobelli A, Rubiano F, St-Onge M-P, Heymsfield SB. New bioimpedance analysis system: improved phenotyping with whole-body analysis. Eur J Clin Nutr. 2004;58:1479-84.
11. McCarthy HD, Cole TJ, Fry T, Jebb SA, Prentice AM. Body fat reference curves for children. Int J Obes. 2006;30:598-602.
12. Dai S, Labarthe DR, Grunbaum JA, Harrsit RB, William H. Longitudinal analysis of changes in indices of obesity from age 8 years to age 18 years. Am J Epidemiol. 2002;156:720-9.
13. Fuller NJ, Fewtrell MS, Dewit O, Elia M, Wells JCK. Segmental bioelectrical impedance analysis in children aged 8-12 y: 1. The assessment of whole-body composition. Int J Obes Relat Metab Disord. 2002;26:684-91.
14. Fuller NJ, Fewtrell MS, Dewit O, Elia M, Wells JCK. Segmental bioelectrical impedance analysis in children aged 8-12 y: 2. The assessment of regional body composition and muscle mass. Int J Obes Relat Metab Disord. 2002;26:692-700.
15. Mueller WH, Harrist RB, Doyle SR, Labarthe DR. Percentiles of body composition from bioelectrical impedance and body measurement in U.S. adolescents 8-17 years old: Project HeartBeat! Am J Hum Biol. 2004;16:135-50.

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以生物電阻法評估日本兒童各部位體組成

為釐清部位體組成在成長期之模式，俾有助於兒童肥胖之管理，本研究以生物電阻法測量 685 位日本國小學童(6-11 歲)之體脂肪與肌肉組織。測量全身及身體不同部位的體脂率、脂肪質量及肌肉質量，並探究它們的成長模式。結果顯示，女生的全身體脂率較男生高，且隨年齡增長，差距越大。同時發現身體不同部位的體脂率、脂肪質量及肌肉質量之成長模式與性別差異和全身類似。在所有年齡層中，左肢的平均體脂率均較右肢高。在男生及女生中，身體質量指數與體脂率都存在很強的相關性。總之，在孩童期，體組成隨年齡的增長及性別間的差異，在所有身體部位都是相似的。慣用的肢體對體組成之效應在幼年就顯現。對於了解兒童時期體組成與監控肥胖狀況，累積身體各部位體組成之資料是必需的。

關鍵字：生物電阻法、部位體組成、脂肪、肌肉、兒童