O R I G I N A L A R T I C L E

Body fat measured by bioelectrical impedance in Hong Kong Chinese children

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Objective To establish reference standards for percentage body fat measured in Hong Kong Chinese children, by methods involving bioelectrical impedance analysis.

Design Cross-sectional study.

Setting Thirty-six randomly selected primary and secondary schools and a teaching hospital in Hong Kong.

Participants A total of 14 842 students randomly selected from the schools and two additional small convenience samples of subjects.

Main outcome measures Percentage body fat was measured with the Tanita Body Composition Analyzer (Model no. BF-522) and percentile curves were constructed using the LMS method. In one separate small sample of children, repeatability of the percentage body fat measurement was assessed at different times of the day by BF-522 bioelectrical impedance analysis. In another sample, assessment was by the BF-522 and two other models (BC-418 and BF-401) consecutively to test the agreement of percentage body fat values obtained by the three different models.

Results The percentage body fat values and percentile curves are presented. From the age of 6 to 18 years, the percentage body fat remained fairly stable in boys, but increased steadily in girls. The mean difference in percentage body fat measured with BF-522 at different times of the day was around 1% (95% limits of agreement: -4% to +8%). The mean differences in readings obtained from the BC-418 and BF-522 devices were -3.5% and 1% in boys and girls, respectively. The 95% limits of agreement were particularly wide in boys (-15% to 8%).

Conclusions Reference values for percentage body fat of Chinese children and adolescents are provided. Caution needs to be exercised however, given that readings obtained at different times of the day vary and data obtained by different makes and models of bioelectrical impedance analysis machines may not be interchangeable.

Key words
Body fat distribution; Child; Electric impedance; Reference values

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Introduction

Childhood obesity is a growing public health problem in Hong Kong. Numerous studies have tracked body fat from childhood to adulthood,[1] and showed that the need for prevention and treatment becomes evident at an early age. To initiate preventive or treatment programmes, assessing whether a child has excessive body fat is the first step. Among the many methods devised for this purpose, determination of body mass index (BMI) is the most widely used surrogate for which both local and international reference standards are available.[2,3] Body mass index, however, does not distinguish between increased lean mass, bone, and fat. A very muscular person can be misclassified as overweight, whereas someone with a small-boned frame and slight skeletal muscles but having a large fat mass may be classified as having a healthy body weight. Measurement of skinfold thickness is a long-established clinical method for estimating subcutaneous body fat, but requires specially trained operators. Several other methods used for measuring body fat, including underwater weighing, dual-energy X-ray absorptiometry (DXA), magnetic resonance imaging, and air-displacement plethysmography, are all complicated and too expensive for routine clinical use.

Bioelectrical impedance analysis (BIA) is a simple, convenient, and inexpensive method for assessing body composition, which has gained increasing popularity in the past decade. The method depends on measuring the resistance (impedance) to an electrical current travelling through body tissues. Fat-free mass (FFM) contains high levels of water and electrolytes, and acts as a conductor of electrical currents, whereas fat mass is comparatively anhydrous and acts as a resistor to the flow of electrical current. Thus, FFM and fat mass can be worked out by applying specific equations according to sex, age, height, weight, and electrical impedances. Due to the simplicity and relatively low costs, nowadays BIA machines are widely used by health care researchers, weight control clinics, and fitness trainers for the estimation and monitoring of fat mass, which is then denoted as the percentage body fat (PBF). Notably, recent papers have begun to use PBF measured by BIA as the 'gold standard' to gauge other clinical measures of childhood obesity.[4,5] Nevertheless, BIA methods are not standardised and the data on PBF application to children are scanty and fragmented. To date, only one set of children's PBF percentile charts is available in the English literature.[6] These are based on data from an opportunistic sample of Caucasian children (1116 boys and 869 girls) in three relatively affluent areas in England with a lower obesity rate than the current British national average. Since it is known that differences in body composition may exist in different ethnic groups,[7] these percentile charts may not be applicable to children of other ethnicity. This study was therefore carried out to establish reference standards for PBF measured by BIA for local Hong Kong Chinese children.

應用物電阻抗量度香港華籍青少年的體脂

目的 應用物電阻抗分析找出香港華籍青少年體脂百分比的參考數值。

設計 橫斷面研究。

安排 香港隨機抽樣選出的36間小學和中學，以及一所教學醫院。

參與者 從學校再隨機選出14 842位學生，並從教學醫院便利抽樣另外兩組青少年。

主要結果測量 使用Tanita Body Composition Analyzer（BF-522型號）及LMS方法，量度參與者的體脂百分比，並得出百分比分佈曲線。在同日的不同時間內，應用物電阻抗重複量度其中一組便利抽樣青少年的體脂百分比。至於另一組，則連續使用三種不同型號（BF-522、BC-418、BF-401）量度體脂百分比來測量其一致性。

結果 分析得出體脂百分比數值和百分比分佈曲線。男性青少年由6歲至18歲的體脂百分比都頗為穩定，但在同一組年齡的女性中則見穩定上升。在同日的不同時間應用BF-522型號量度體脂百分比的平均差異約為1%（95%置信區間：-4%至+8%）。比較BC-418及BF-522型號得出的平均差異，男性為-3.5%，女性為1%。而男性的95%置信區間尤其大（-15%至8%）。

結論 本研究得出華籍青少年體脂百分比的參考數值。可是由於所量度的數值會隨着同一天內不同的時間和使用不同的型號有所改變，必須小心闡釋這些參考數值。

Methods

Subjects

A list of all the schools in Hong Kong was compiled from data held by the Department of Education. One primary school and one secondary school were selected randomly from each of the 18 districts in Hong Kong. Two classes in each grade were then randomly selected from the schools. All students of the selected classes were invited to join the study. A fact sheet explaining the purpose and procedure was given to each student and their parents. A total of 7% of the primary and 10% of the secondary school students declined to participate. The parents of all participants were invited to complete a questionnaire providing demographic information including gestation, birth weight, feeding patterns in infancy, and family or personal history of risk factors for obesity. The study was approved by the University's ethics committee.

Measurement of anthropometric parameters

A team of eight trained research staff visited the selected schools on a pre-arranged date to collect the anthropometric data. Standing height without shoes was measured using a Harpenden Stadiometer (Holtain, Crymych, UK) to the nearest 0.1 cm. Body weight and PBF were measured using a portable Tanita body fat monitor/scale (Model BF-522, 4-contact electrodes with two on each foot; Tanita, Japan). Waist circumference (WC) was measured to the nearest 0.1 cm midway between the lowest rib and the superior border of the iliac crest with an inelastic measuring tape.

Repeatability of the bioelectrical impedance analysis measurement

The repeatability of PBF measurement by the BF-522 was tested using a convenience sample of 118 children, who were consecutively admitted to our sleep laboratory for an ongoing community-based epidemiological study. The same operator measured PBF of subjects before and after meals on the same day.

Comparison of the Tanita Model BF-522 with BF-401 and BC-418 models

Measurements of PBF were carried out using three different devices from Tanita (BF-522, BF-401, and

TABLE 1. Mean (standard deviation) percentage body fat and anthropometric measurements, according to sex and age in 14 646 Hong Kong Chinese children

Age (years)	No.	Weight (kg)	Height (cm)	Body mass index (kg/m²)	Waist circumference (cm)	% Body fat
Boys						
6	401	23.6 (4.7)	120.4 (5.5)	16.2 (2.4)	53.7 (5.4)	17.3 (4.9)
7	518	26.4 (6.1)	125.7 (5.9)	16.6 (2.7)	55.4 (6.6)	17.9 (5.4)
8	573	29.3 (6.6)	130.7 (5.8)	16.9 (2.9)	56.9 (6.8)	18.7 (5.9)
9	630	32.7 (7.8)	135.6 (5.9)	17.6 (3.2)	59.5 (7.8)	19.7 (6.7)
10	627	37.5 (9.6)	141.2 (6.9)	18.6 (3.7)	62.4 (9.1)	20.6 (6.9)
11	644	41.8 (10.6)	147.3 (7.9)	19.1 (3.6)	64.0 (9.2)	19.7 (7.4)
12	728	46.6 (11.9)	154.1 (8.6)	19.4 (3.7)	64.6 (9.1)	18.0 (7.1)
13	657	51.1 (11.3)	161.2 (7.8)	19.6 (3.5)	65.3 (8.2)	17.1 (6.4)
14	632	54.9 (10.8)	166.3 (6.9)	19.8 (3.4)	66.0 (7.7)	17.4 (6.1)
15	558	59.1 (12.0)	169.8 (5.4)	20.4 (3.8)	68.1 (8.7)	18.9 (6.3)
16	579	60.6 (11.1)	170.8 (5.7)	20.7 (3.4)	68.8 (8.2)	19.7 (6.0)
17	553	61.5 (10.9)	171.9 (5.7)	20.8 (3.4)	69.4 (7.8)	20.2 (6.0)
18	370	62.3 (10.9)	171.6 (5.6)	21.1 (3.3)	70.2 (7.6)	19.1 (4.0)
Girls						
6	324	21.8 (3.8)	118.7 (5.1)	15.4 (1.9)	51.4 (4.2)	14.1 (4.8)
7	427	24.9 (5.1)	124.3 (5.5)	16.0 (2.5)	53.3 (5.4)	15.4 (5.7)
8	468	27.8 (6.0)	129.4 (6.3)	16.3 (2.5)	54.6 (5.8)	16.2 (5.9)
9	556	30.8 (6.4)	135.1 (6.3)	16.8 (2.6)	56.7 (6.0)	17.2 (6.1)
10	581	35.3 (8.5)	141.7 (7.0)	17.4 (3.1)	58.5 (6.9)	18.3 (6.5)
11	584	40.1 (9.3)	148.9 (7.0)	18.0 (3.2)	60.2 (6.8)	19.3 (6.6)
12	749	44.1 (9.4)	153.1 (6.2)	18.7 (3.3)	61.2 (7.0)	21.1 (6.9)
13	637	47.8 (8.5)	156.2 (5.4)	19.6 (3.1)	62.2 (6.5)	23.5 (6.8)
14	656	49.0 (8.6)	157.6 (5.4)	19.7 (3.0)	62.3 (6.2)	24.3 (6.4)
15	600	50.5 (9.1)	158.3 (5.3)	20.1 (3.3)	63.0 (6.7)	25.4 (6.5)
16	640	50.7 (8.9)	158.3 (5.3)	20.2 (3.3)	63.2 (6.4)	25.5 (6.3)
17	568	51.4 (9.2)	158.9 (5.7)	20.3 (3.3)	63.5 (6.3)	25.7 (6.2)
18	386	51.3 (8.1)	158.6 (5.6)	20.4 (2.9)	63.8 (5.6)	25.5 (5.7)

BC-418) in a convenience sample of 633 healthy children attending the clinic for a regular check-up. Model BF-522 was used in the current study. Model BF-401 had been previously validated against the DXA model by our group.[8] Model BC-418 is the newest model (8-contacts; two on each hand and foot) and is deemed to be superior to previous 4-contact models.[9] Measurements by the three machines was conducted in random order, one after another by three operators.

Statistical analyses

All statistical analyses were performed using the Statistical Package for the Social Sciences (Windows version 14.0; SPSS Inc, Chicago [IL], US). Relationships between the anthropometric measurements were assessed with the Pearson correlation test. Percentile curves were constructed for PBF results and smoothed using the LMS method.[10] The Bland-Altman plots were used to assess agreement of PBF values obtained by the BF-522 device at different times of the day. The same method was employed to evaluate the agreement between PBF results obtained with different BIA machines.

Results

Sex- and age-specific mean weight, height, BMI, WC, and PBF values are shown in Table 1. Percentage body fat correlated more closely with weight, height, WC, and BMI in girls than boys (r=0.40, 0.06, 0.64, 0.68 and 0.86, 0.52, 0.88, 0.95 for boys and girls, respectively).

Smoothed sex- and age-specific PBF percentiles are shown in Fig 1. Percentage body fat remains fairly stable from age 6 to 18 years in boys, with only a slight decrease at 13 to 14 years and a slow steady increase after age 14 years. In contrast, in girls PBF increases steadily from 6 to 18 years. For comparison with other published data, the mean PBF values were

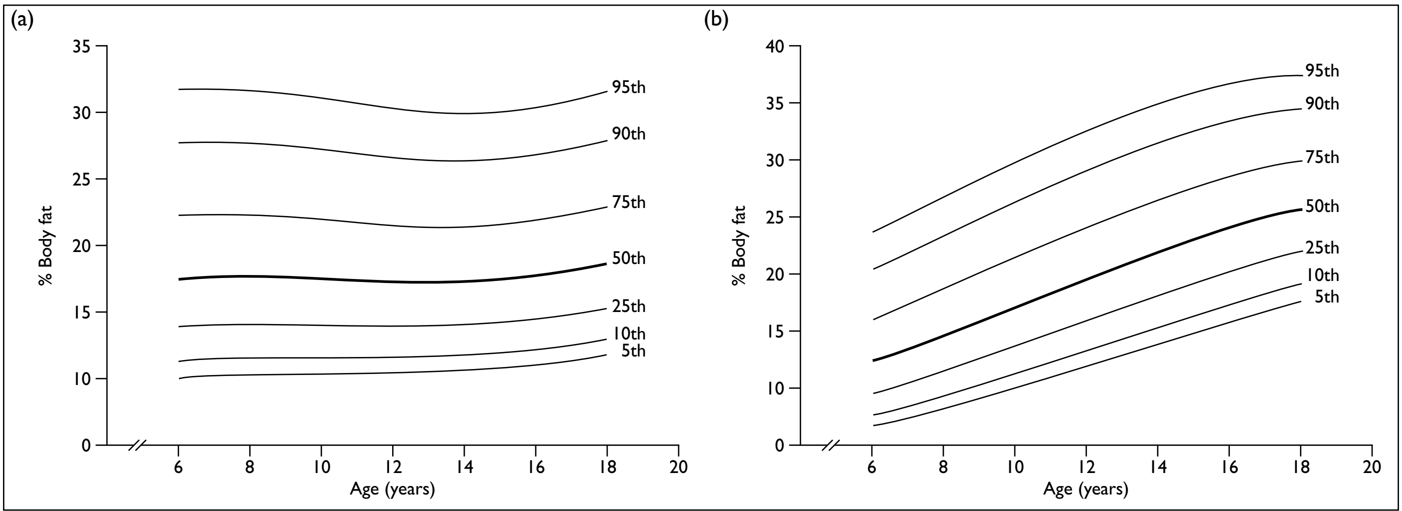


FIG 1. Smoothed percentile curves for percentage body fat of (a) boys (n=7470) and (b) girls (n=7176)

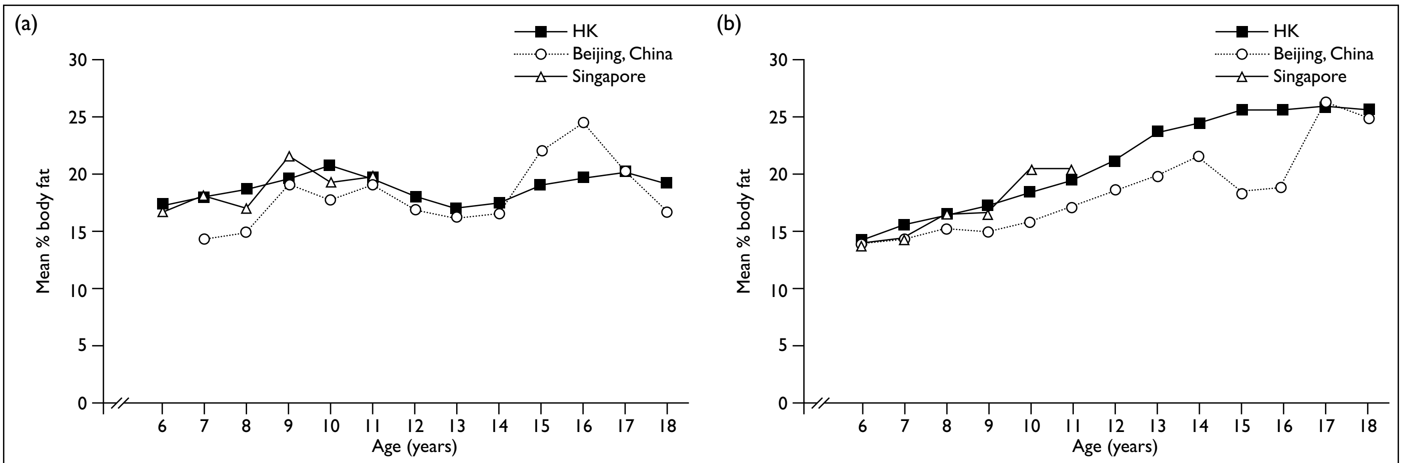


FIG 2. Mean percentage body fat according to age among three studies in Chinese children: (a) boys and (b) girls
Beijing[11]: 4-18 years old; 435 boys and 454 girls; sampling method not described; measured in 1999 using the Tanita TBF-300
Singapore[4]: Chinese children of 6-11 years old; 321 boys and 302 girls; proportionate, stratified random sample from a school; measured in 2002 using the Tanita TBF-300

plotted against Beijing[11] and Singapore[4] data (Fig 2). In general, Hong Kong children aged below 15 years had a slightly higher (0.7-3.7%) mean PBF than those reported in the Beijing study. The mean PBF of children in the Singapore study (6-11 years olds only) was almost identical to that of Hong Kong subjects in this age range.

A comparison with British percentile charts[6] shows that the 50th percentile for Hong Kong boys largely overlaps that of British boys until they are 14 years old. At that point the curves start to diverge; the curve for Hong Kong boys getting progressively higher. The Hong Kong girls' 50th percentile curve is in general lower than that of UK girls, but the difference becomes progressively smaller and disappears at age 15 years. The 95th percentile curve of Hong Kong boys was significantly higher than that of UK boys, whereas for Hong Kong girls the 95th percentile curve was lower at a younger age, but progressively increased and overlapped with the corresponding UK curve in 12 year olds, and was significantly higher after age 12 years (Fig 3).

Repeatability of BF-522

Most of the 118 subjects admitted for sleep study were overweight or obese with mean (±standard deviation [SD]) BMI values being: 23.5±6.7 kg/m^2 and 22.5±5.3 kg/m^2 in boys and girls respectively, which was significantly higher than those in corresponding population samples (19.0±3.6 kg/m^2 and 18.5±3.4 kg/m^2). The results of repeatability of measurements made at different times within a day are shown in Table 2. Although the mean differences were small (approximately 1%), the

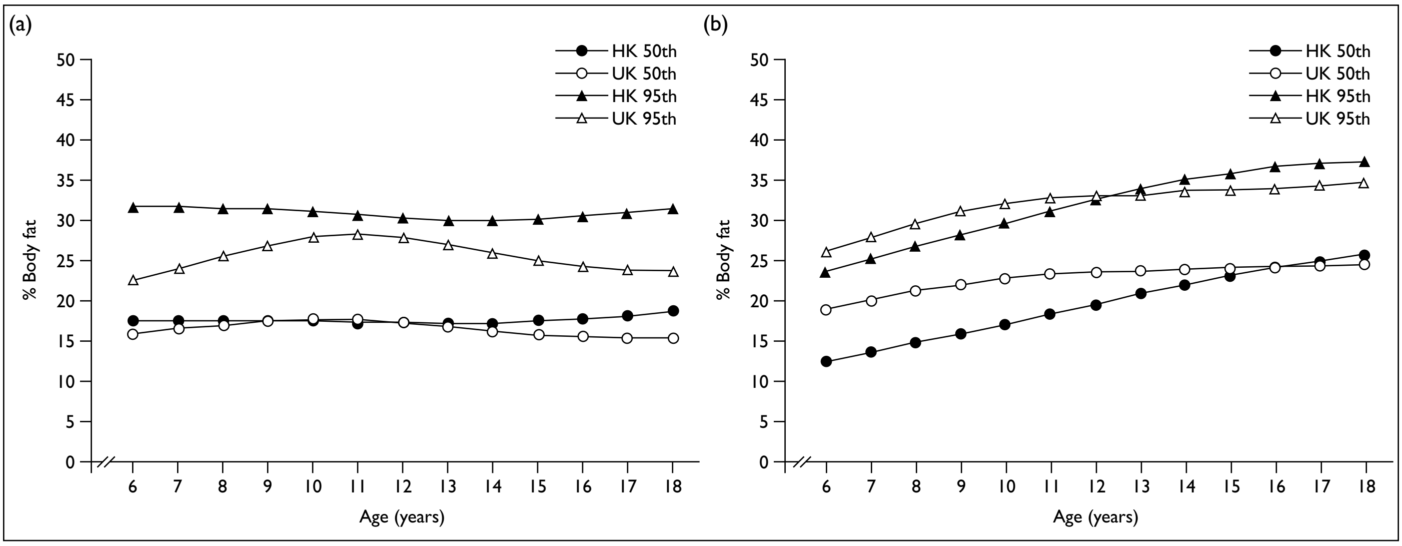


FIG 3. 50th and 95th percentiles for percentage body fat according to age in UK and Hong Kong children: (a) boys and (b) girls

TABLE 2. Repeatability of BF-522 measurements in a cohort of children aged 6 to 18 years

Repeatability	Valid No. included	Mean difference (%)*	95% Limits of agreement†
Before breakfast vs after breakfast	74	0.22	-2.65 to 3.10
Before breakfast vs before lunch	55	1.61	-4.33 to 7.56
Before breakfast vs after lunch	60	1.14	-4.45 to 6.72
Before lunch vs after lunch	53	-0.82	-4.24 to 2.61

* Mean difference in percentage body fat measured at two different times
† The 95% limits of agreement correspond to the mean difference±2 standard deviations

95th percentile limits of agreement are wide (up to 7.6%).

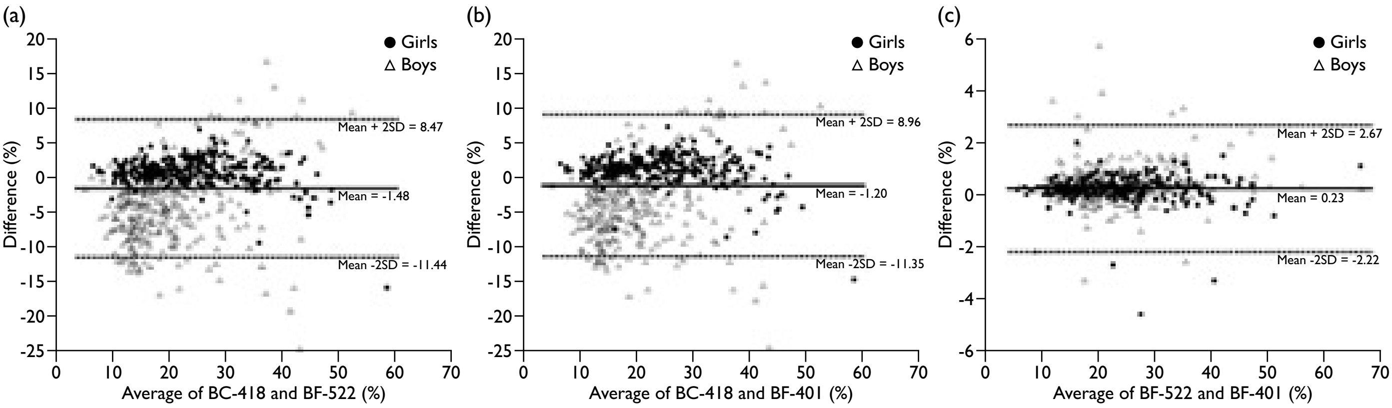
Comparison of BF-522, BC-418, and BF-401

In another convenience sample, the respective mean (±SD) BMI values for the 341 boys and 284 girls were 19.4±4.1 kg/m^2 and 19.3±4.1 kg/m^2, and were not significantly different from those in the population samples. The Bland-Altman plots of difference in PBF between any two of the three models versus the mean of the corresponding two models are shown in Fig 4. The range of agreement between the BC-418 and either the BF-522 (95% limits of agreement ranging from -15% to +8%) or the BF-401 (ranging from -15% to +9%) was wide. The differences were especially remarkable in boys (P values for comparisons of the mean difference between girls and boys were both <0.001). The BC-418 gave significantly lower PBF readings than the BF-522 or BF-401 in boys. In contrast, the agreement was much better between the BF-522 and BF-401 (95% limits of agreement, -2% to +3%).

Discussion

We present tables and percentile charts of PBF for Hong Kong children aged 6 to 18 years. The data were collected from a large representative sample of local Chinese children and may serve as reference standards for further research on PBF in such children. Using the International Obesity Task Force cut-offs,[12] the proportions of overweight and obese children in our sample were 13% and 4%, respectively. Our study showed that PBF remains fairly stable from age 6 to 18 years in boys; there is only a slight decrease at 13 to 14 years and a slow steady increase after the age of 14 years. In girls, PBF increases steadily from 6 to 18 years of age, which is in accord with our previous study in a smaller sample[8] and other studies in different ethnic populations.[6,13,14] In boys however, the PBF curves derived from this study appear to differ from results reported from Britain.[6] The present study showed that PBF continued to increase gradually with increasing age after the age of 14 years, whereas it continued to decrease in the UK sample. Whether this difference is due to genetic, lifestyle, or other factors is unknown. Our previous study included 1234 male and 1139 female aged 7 to 16 years randomly sampled from eight local schools. The present study included 7470 male and 7176 female students aged 6 to 18 years randomly selected from one primary school and one secondary school, from each of the 18 districts in Hong Kong. So the large sample in the present study should be more representative of the entire Hong Kong student population.

A comparison of the mean PBF in this study with Chinese children from Beijing[11] and Singapore[4] revealed great similarity among the three populations. Both the Beijing and Singapore studies used a TBF-300



Agreement	Valid No. included	Mean difference (%)*	95% Limits of agreement†
(a) BC-418 vs BF-522			
All	625	-1.48	-11.44 to 8.47
Girls	284	0.98	-3.19 to 5.16
Boys	341	-3.53	-14.94 to 7.88
(b) BC-418 vs BF-401			
All	571	-1.20	-11.35 to 8.96
Girls	262	1.19	-3.25 to 5.64
Boys	309	-3.23	-14.98 to 8.52
(c) BF-522 vs BF-401			
All	579	0.23	-2.22 to 2.67
Girls	262	0.15	-1.87 to 2.16
Boys	317	0.29	-2.45 to 3.04

* Mean difference between PBF measured by different pairs of machines
† The 95% limits of agreement correspond to the mean difference±2 standard deviations

FIG 4. Bland-Altman plots of agreement in percentage body fat (PBF) between (a) BC-418 and BF-522, (b) BC-418 and BF-401, and (c) BF-522 and BF-401, with 95% limits of agreement. Agreements between PBF measured by three bioelectrical impedance analysis machines are shown in the table

device, which is equipped with the same equations as the BF-522 machine used by us (information from the manufacturer). However, no further comparison regarding the distribution of PBF could be made, as percentiles were not reported in the other two papers.

Previous studies of body composition in children reported ethnic differences among white, black, Hispanic, and South Asians.[14,15] To compare our data with the reference standards from other ethnic groups is complicated, because of the different sampling methods and BIA machines used. Nevertheless, comparison revealed that the 50th percentile curve of Hong Kong boys largely overlaps with the British curve until the age of 14 years. In Hong Kong girls, the 50th percentile curve was in general lower than that in UK girls, although the difference became progressively smaller and disappeared at the age of 15 years. It is worth noting that the UK study intentionally recruited subjects from more affluent areas in England, which contained less overweight/obese children. This was because they wanted to match their sample with the British 1990 reference sample.[6] Therefore, a comparison of our present PBF percentile charts with the British 2006 PBF reference charts may not reflect a true difference between the children.

Due to the simplicity and convenience of using BIA to estimate body fat, it would be ideal if these reference standards can also be used to define and monitor each individual child's status. For several reasons however, this has to be approached with caution. First, unlike what is known about BMI and WC,[16,17] the healthy range of PBF has not been directly explored, which means that there are no meaningful cut-off values to indicate cardiovascular and metabolic risk. Previous studies have shown that a minimum reduction of 0.5 BMI SD score is required to produce significant improvements in indices of blood pressure, lipid profiles, and insulin resistance.[18] Studies evaluating whether the BIA can be used for serial assessment of body composition during courses of weight reduction have provided conflicting results; some report good accuracy compared to DXA,[19,20] while others show poor performance.[21,22] Due to the lack of clinical correlations, further studies are needed before reliable advice can be offered in terms of what decrease in PBF is meaningful with regard to cardiovascular and metabolic risk reduction.

The second reason for caution is that BMI is calculated using a uniform formula that includes height and weight, both measurements being standard parameters, whereas this is not the case with BIA. Using BIA to measure PBF depends on prediction equations worked out by different researchers. Different manufacturers and models adopt different equations, some of which are unavailable for comparison for reasons of commercial confidentiality. So the interchangeability of available data from different makes and models remains questionable. Previously we had validated one model (TBF-401) against the DXA in children and found that the readings obtained with the former were within 2% of the DXA readings.[8] We used the Tanita Body Composition Analyzer (BF-522) for the present study because it is light in weight, has good portability, and the equation it uses for body composition analysis is identical to that used in the TBF-401 device (personal communication). The latest 8-electrode Tanita BC-418 model has been reported to achieve better correlation with DXA measurements (r=0.87 and 0.82 respectively) than the Tanita BC-310 (a previous 4-electrode leg-to-leg model) tested in 40 subjects aged 6 to 64 years.[9] In our cross-validation of the three different machines in this study, the range of agreement was much narrower for the BF-522 and BF-401 (same equations) than for the BF-522 and BC-418 (different equations). Thus, the data obtained from different models may not always be interchangeable and further research is warranted to determine which models most accurately reflect PBF in children.

Previous studies have yielded conflicting results with regard to the impact of hydration status. Deurenberg et al[23] reported significant changes in whole-body impedance following fluid intake. In contrast, Dixon et al[24] showed that drinking 591 mL water or carbohydrate/electrolyte drink prior to BIA assessment had no effect on lower body impedance, and resulted in only a very slight (0.5%) overestimation of PBF that was of little practical significance. In a separate sample of children, BIA measurements were performed repeatedly during the day, and yielded PBF readings that varied significantly (up to 8%). One caution applicable to our sample of subjects was that the children were admitted for sleep study and most were overweight or obese. Hence data derived from this group may not be applicable to all children. For practical reasons, all our measurements were in the morning 2 to 4 hours after breakfast. Therefore, for comparison with the present reference standards, the measurement should also be undertaken in the morning, 2 hours after breakfast and before lunch. For monitoring PBF in individual children, measurements taken at the same time on different days will likely be more meaningful.

In conclusion, reference values for the PBF in Chinese children and adolescents are provided. The 85th percentile of PBF may tentatively be considered a clinically useful cut-off for the definition of excessive body fat. However, different makes and models of the BIA machines may give significantly different readings, and therefore corresponding results may not be interchangeable.

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