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## ORIGINAL COMMUNICATION

# A comparison of international references for the assessment of child and adolescent overweight and obesity in different populations†

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**Objective:** To compare different references assessing child and adolescent overweight and obesity in different populations.
**Design:** Comparison cross-sectional study.
**Setting:** The United States, Russia, China.
**Subjects:** A total of 6108 American, 6883 Russian and 3014 Chinese children aged 6–18 y.
**Investigation:** Using nationwide survey data from the USA (NHANES III, 1988–1994), Russia (1992), and China (1991), we compared three references: (1) the International Obesity Task Force (IOTF) reference, sex–age-specific body mass index (BMI) cut-offs that correspond to BMIs of 25 for overweight and 30 for obesity at age 18; (2) the World Health Organization (WHO) reference—BMI 85th percentiles for overweight in adolescents (10–19 y) and weight-for-height *Z*-scores for obesity in children under 10; (3) a USA reference—BMI 85th and 95th percentiles to classify overweight and obesity, respectively.
**Results:** Using the IOTF reference and 85th BMI percentiles, overweight prevalence was 6.4 and 6.5% in China, 15.7 and 15.0% in Russia, and 25.5 and 24.4% in the USA, respectively. Notable differences existed for several ages. Kappa (=0.84–0.98) indicated an excellent agreement between the two references in general, although they varied by sex–age groupings and countries. Overweight prevalence was twice as high in children (6–9 y) than in adolescents (10–18 y) in China and Russia, but was similar in the USA. Estimates of obesity prevalence using these three references varied substantially.
**Conclusions:** The references examined produce similar estimates of overall overweight prevalence but different estimates for obesity. One should be cautious when comparing results based on different references.
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**Keywords:** BMI; obesity; overweight; child; adolescent; reference

## Introduction

Child and adolescent obesity is increasing worldwide (WHO, 1998). Most previous studies have used different definitions of child and adolescent obesity, and no standard or reference has been agreed upon internationally. As a result, it is difficult to make meaningful comparisons across countries and studies (Guillaume, 1999; Power *et al*, 1997). Recently a World Health Organization (WHO) consultation on obesity concluded that there is an urgent need to examine obesity in children and adolescents around the world based on a standardized obesity classification system (WHO, 1998). Some recent efforts have been made to fill the gap in the literature (de Onis & Blossner, 2000; Martorell *et al*, 2000; Wang, 2001).

Body mass index (BMI=weight(kg)/height(m)$^2$), a weight-for-height index, has been widely used to measure obesity in adults worldwide (Bray *et al*, 1998; WHO, 1995,1998). The support for using BMI to measure child obesity is increasing rapidly (Cole *et al*, 2000; Dietz & Robinson, 1998; Frisancho, 1990; Himes & Dietz, 1994; Kuczmarski *et al*, 2000; Must *et al*, 1991a; WHO,

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1995,1998). BMI is closely correlated with body fat and long-term health risks in children and adolescents (Power *et al*, 1997; Must & Strauss, 1999). In adults, the BMI cut-off points of 25 and 30 are widely used to define overweight and obesity, respectively. Ample evidence indicates that these cut-offs are good indicators of risks for adverse health outcomes, although the health consequences for overweight children may differ from adults (WHO, 1995,1998). Unlike in adults, BMI varies substantially by age and gender during childhood and adolescence (eg Kuczmarski *et al*, 2000; Must *et al*, 1991a). Thus the cut-offs for children and adolescents should be gender- and age-specific. Different references based on weight-for-height indexes such as BMI and weight-for-height have been proposed to classify child and adolescent body weight status, and these references vary considerably (Cole *et al*, 2000; Frisancho, 1990; Guillaume, 1999; Himes & Dietz, 1994; Kuczmarski *et al*, 2000; Must *et al*, 1991a; WHO, 1995).

An international reference will be useful for making appropriate comparisons across studies and monitoring the global obesity epidemic. To meet such demands, a WHO committee recommended using the 85th BMI percentile developed based on US data collected in the 1970s to define adolescent (10–19 y) overweight for international use (WHO, 1995). Recently the Childhood Obesity Working Group of the International Obesity Task Force (IOTF) proposed a new international BMI reference to define overweight and obesity for children and adolescents aged 2–18 y (Cole *et al*, 2000). Limited efforts have been made to compare the use of these references in different populations. Whether these references are appropriate to classify overweight and obesity in developing countries, where children's BMI distributions are much lower and children mature later than the reference populations, is still a matter of debate (Wang & Adair, 2001; Wang *et al*, 2000a,b; WHO, 1995).

Our primary objective was to compare the IOTF and WHO references for assessing overweight in children and adolescents from different populations. We also compared the IOTF reference for obesity with another widely used reference—the BMI 95th percentile developed by Must *et al* using US data (Himes & Dietz, 1994; Must *et al*, 1991a,b). Data for children and adolescents from China, Russia and the USA were used. Both developing and industrialized countries located on different continents were included. The USA was selected as an example of an industrialized country, Russia, a middle-income country, and China, a developing country. Evidence indicates that levels of obesity vary substantially among these three countries (Popkin & Doak, 1998; Wang, 2001; WHO, 1998).

## Materials and methods

### Subjects

Children aged 6–18 y were included. They were separated into two age groups, children (6–9 y) and adolescents (10–18 y). The sample size was 3014 for China, 6883 for Russia, and 6108 for the USA. Children under 6 y were not included due to two considerations: (a) BMI may not be a good indicator of body fat for preschool children (WHO, 1995)—the WHO recommends use of weight-for-height and weight-for-age *Z*-scores to define overweight and underweight for preschool children, and this practice has been widely used (WHO, 1995); and (b) age 6–7 is the approximate age when adiposity rebound occurs and the exact age may vary among populations (Rolland-Cachera *et al*, 1984; Whitaker *et al*, 1998).

### Data sets

***The US Third National Health and Nutrition Examination Surveys (NHANES III, 1988–1994).*** The third NHANES, conducted between 1988 and 1994, was a cross-sectional representative sample of the US civilian noninstitutionalized population aged 2 months and older. NHANES III contains data for a sample of 33 994 people, and it over-sampled black and Mexican American people, children under 5, and the elderly ($\geq$60 y). Standardized protocols were used for all interviews and examinations. Data on weight and height were collected for each individual in the full mobile examination center (MEC) through direct physical examinations. Detailed descriptions of the sample design and the operation of the survey are published elsewhere (US DHHS, 1994).

***The Russian Longitudinal Monitoring Survey (RLMS, 1992).*** The RLMS survey was the first nationally representative household survey in the Russian Federation. All members of more than 6400 households from all regions of Russia were surveyed eight times between 1992 and 1998. Weight and height were measured following a protocol similar to the one used in the US NHANES surveys. Details about the RLMS have been described elsewhere (Zohoori *et al*, 1998). The 1992 data were used in our study.

***The China Health and Nutrition Surveys (CHNS 1991).*** The CHNS longitudinal surveys covered eight provinces that vary substantially in geography, economic development, public resources and health indicators. A multistage, random-cluster process was used to draw the sample in each province. Although the CHNS sample is not nationally representative, it provides a broad-based indication of the situation in China. Anthropometric measurements were carried out by trained health workers following a reference protocol similar to the US NHANES protocols. Weight was measured in light, indoor clothing to the nearest 0.1 kg with a beam balance scale. Height was measured without shoes to the nearest 0.1 cm using a portable stadiometer. Details about the CHNS have been described previously (Wang *et al*, 2000a,b). The 1991 data were used.

### References for classifying overweight and obesity in children and adolescents

***The International Obesity Task Force (IOTF) reference.*** To define 'overweight' and 'obesity' among children aged 2–18 y, the IOTF recently published a series of sex–age-specific BMI cut-offs, which are developed from sex-specific BMI–age curves that pass through a BMI of 25 for overweight and 30 for obesity at age 18 (see Figure 1 and Table 1; Cole *et al*, 2000). The IOTF reference has been recommended for international use due to its unique strengths. First, it is based on large data sets from six countries or regions, including Brazil, Britain, Hong Kong, The Netherlands, Singapore and the USA. Second, the BMI cut-offs are linked to adult cut-offs for overweight and obesity, which are good indicators of risks for adverse health outcomes (WHO, 1995,1998). On the other hand, there are also concerns about this reference (Wang *et al*, 2000a,b). For example, there is great variation in the prevalence of overweight and obesity across the six countries that made up the IOTF reference population. In addition, little is known about whether (or how) BMIs above these BMI cut-offs are related to health consequences for children, and whether such consequences vary across populations. However, other existing BMI references share these limitations as well.

***The Must, Dallal and Dietz (MDD) reference.*** Using the US NHANES I data collected in 1971–1974, Must, Dallal and Dietz calculated BMI percentiles for people aged 6–74. They

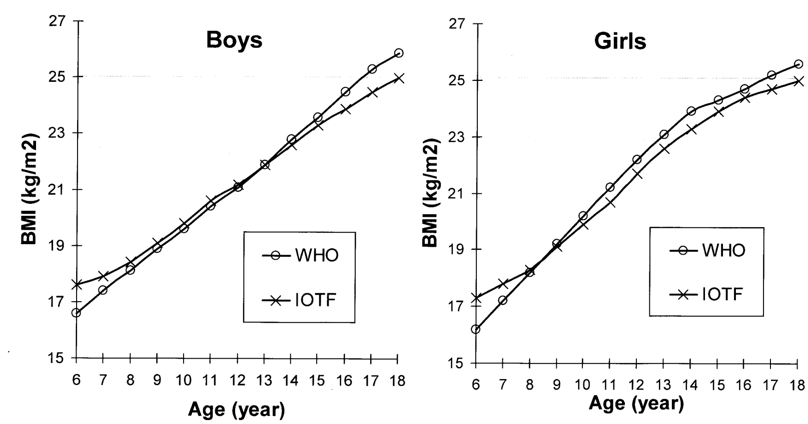


**Figure 1** The IOTF and WHO references for overweight for boys and girls aged 6–18 y old. IOTF reference: sex–age-specific BMI cut-offs that correspond to BMI = 25 at age 18. WHO reference: for adolescents aged 10–18, sex–age-specific BMI 85th percentile from US NHANES I data; for children under 10, the BMI-for-age 85th percentile ('MDD reference') was called 'WHO reference' for simplicity.

**Table 1** Different references: classifications of child and adolescent overweight and obesity[a]

| | *International Obesity Task Force: IOTF reference (Cole et al, 2000)* | *World Health Organization: WHO reference (WHO, 1995)* | *Must, Dallal and Dietz: 'MDD reference' (Must et al, 1991a,b)* | *Note* |
|---|---|---|---|---|
| Data and reference populations | Large survey data sets from the US, Brazil, Britain, Hong Kong, The Netherlands and Singapore | US NHANES I data | US NHANES I data | |
| Overweight | | | | |
| Child (6–9 y) | BMI-for-age cut-offs derived from BMI–age curves passed BMI of 25 at age 18 | No reference, and see below 'obesity' | BMI 85th percentile | |
| Adolescent (10–18 y) | BMI-for-age cut-offs derived from BMI–age curves passed BMI of 25 at age 18 | BMI 85th percentile | BMI 85th percentile | The WHO and MDD references are the same |
| Obesity | | | | |
| Child (6–9 y) | BMI-for-age cut-offs derived from BMI–age curves passed BMI of 30 at age 18 | Weight-for-height (> 2 *Z*-scores)[a] | BMI 95th percentile | |
| Adolescent (10–18 y) | BMI-for-age cut-offs derived from BMI–age curves passed BMI of 30 at age 18 | BMI 85th percentile and triceps skinfold thickness 90th percentile | BMI 95th percentile | The WHO reference was not used[b] |

[a]WHO recommended use the term of 'overweight', but they acknowledged that 'on a population-wide basis, high weight-for-height can be considered as an adequate indicator of obesity', although it recommended not to use the term of 'obesity' for children to describe high weight-for-height on an individual basis (WHO, 1995, pp 189, 195). A *Z*-score of 2 corresponds to the 97.7th percentile.
[b]Due to lack of data on triceps skinfold thickness and few previous studies having used this reference.

recommended use of BMI 85th and 95th percentiles to classify child and adolescent 'overweight' and 'obesity', respectively (Must *et al*, 1991a,b). These BMI cut-offs (called 'MDD reference' in this paper) have been recommended by several health organizations such as a WHO Expert Committee and the Expert Committee on Clinical Guidelines for Overweight in Adolescent Preventive Services in the US (Himes & Dietz, 1994; WHO, 1995). This reference has been widely used worldwide (El-Tawila *et al*, 1999; Ge, 1999; Himes & Dietz, 1994; Monteiro & Conde, 1999; Troiano & Flegal, 1999; Wang *et al*, 1998).

***The World Health Organization (WHO) reference.*** A WHO Expert Committee recommended the use of different weight-for-height indexes to classify overweight and obesity in children and adolescents—to use BMI in adolescents and weight-for-height *Z*-score in children (WHO, 1995). For adolescents (10–19 y), to define 'overweight', the committee recommended using those sex–age-specific BMI 85th percentile developed by Must *et al* (1991a,b); for 'obesity', using both sex–age-specific BMI 85th percentile and triceps skinfold thickness 90th percentile. However, data on triceps skinfold thickness are not usually available from large-scale surveys, especially in developing countries such as our Russian data. In addition, measurement of triceps skinfold thickness may not be reliable (Himes, 1991). To our knowledge, few studies have used this reference. In contrast, the MDD reference (BMI 95th percentile) has been widely used. Therefore, the WHO obesity reference was not used in our comparisons. We chose to compare the IOTF obesity reference with the MDD reference.

For children under 10, the WHO committee recommended use of weight-for-height ($>Z$-scores 2) to define 'overweight'. (Note: a *Z*-score of 2 corresponds to the 97.7th percentile; a *Z*-score of 1.04 to the 85th percentile; and 1.65 to the 95th percentile.) They recommended that the term 'obesity' not be used for children on an individual basis, and did not provide a reference for 'obesity'; but they stated that 'on a population-wide basis, high weight-for-height can be considered as an adequate indicator of obesity'. To make appropriate comparisons, we chose to compare the prevalence calculated using 2 *Z*-scores with obesity prevalence calculated using the IOTF and MDD references.

Most recently, the US National Center for Health Statistics (NCHS), the Centers for Disease Control and Prevention (CDC) updated the growth charts and provided new BMI percentiles—the new CDC Growth Charts (Kuczmarski *et al*, 2000). They recommended the use of BMI for children and adolescents over age 2. In our analysis (not presented), we found that in general the old and new BMI cut-offs were similar and they generated consistent estimates of overweight prevalence. However, the new CDC BMI cut-offs have not been endorsed for international use. Therefore, we chose to use the original BMI cut-offs developed by Must *et al* (1991a,b) and recommended by the WHO (1995).

The three original BMI references were provided only for 6-month or whole-year age intervals. To use age precisely, we fitted a polynomial regression of the BMI curves to the ages of boys and girls (the regression equations are available from the authors by request). Each of the six sex-specific curves had an excellent fit ($r^2>0.999$; sum of squared residuals $<0.07$). The predicted and original BMI cut-offs matched perfectly. An advantage of using the predicted BMI values is that we could round children's ages to 0.1 y.

### Statistical analysis

We calculated BMI for all subjects using their measured weight (kg) and height (m). Each child was classified as overweight or obese by comparing his/her BMI with the predicted BMI cut-offs for her/his age. *Z*-scores were computed for each child under 10 y old using the ANTHRO software (Sullivan, 1990). First, we estimated the prevalence of overweight (obesity was included) in each country using each reference. Since the prevalence of obesity is very low in the China sample, we chose to examine the combined prevalence of overweight and obesity for comparisons among our three samples. Examining the difference in prevalence within countries among the references, we assessed the agreement at the population level. Then, we calculated the kappa coefficient, a statistic that measures agreement at an individual level. (Note: kappa $=(P_o-P_e)/(1-P_e)$, where $P_e$ = expected probability of agreement by chance and $P_o$ = observed probability of agreement.) Kappa equals 0 when the observed agreement equals that expected by chance and 1 when the agreement is perfect. It is suggested that a kappa $\geq 0.4$ indicates a moderate agreement, and a kappa $\geq 0.8$, a good agreement (Landis & Koch, 1977). Finally, using similar approaches, we compared the IOTF, WHO and MDD obesity references in Russian and American children and adolescents (the prevalence was very low in China). All analyses were performed using SAS Version 8.0 (SAS, Cary, NC, USA) and Stata Version 7.0 (Stata Corp., College Station, TX, USA). For the US NHANES III data, we used Stata survey procedures that accounted for sampling weights to allow generalization of the results to the USA population.

## Results

### General characteristics of each sample

The general characteristics of the three study samples are presented in Table 2. The Chinese children and adolescents were shorter, lighter in body weight, and thinner (BMI) than the Russian and American subjects.

### Comparison of the IOTF, WHO and MDD BMI references for overweight

Table 3 shows that the IOTF and WHO references produced similar estimates for overall overweight prevalence (%) among adolescents, and so did the IOTF and MDD references for children under 10. The difference was about 1 percentage point for China, and 2–3 percentage points for both Russia and the US, where the precedence was greater than that in China. In general, the agreement was better among adolescents than children, better among girls (6–9 y) than boys (6–9 y), and worse among female adolescents than male adolescents. The IOTF reference produced a slightly lower estimate of the prevalence than the MDD reference in children but a slightly higher estimate than the WHO reference in adolescents. In addition, we found that overweight prevalence was higher in children (over double) than in adolescents in both the Chinese and Russian samples but was similar in both age groups for the USA. We further investigated whether the agreement differed by age (Figure 2). All three samples exhibited large differences at ages 6 and 7, and in general the differences increased after age 14 in both the Russian and American subjects. The difference was remarkable in some cases, for example, in the USA, the difference was approximately 5 percentage points for children aged 6 and for adolescents aged 14 and 17–18. Kappa values suggest an excellent agreement between the IOTF and WHO references among adolescents and between IOTF and MDD reference among children (Table 4), although the agreement varied slightly among samples, age groups and genders. The best agreement was found among Chinese adolescent boys (kappa = 0.98) and the poorest agreement was among Russian boys aged 6–10 and female adolescents (kappa $\leq$0.84), which still indicates excellent agreement.

### Comparison of the IOTF and MDD BMI references for obesity in children and adolescents aged 6–18 y

For the Russian and American children and adolescents, we compared the IOTF and MDD references for obesity. As shown in Table 5, the agreement between the two references was poor among children (6–9 y), but was excellent among adolescents (10–18 y). The estimate of overall obesity prevalence using the IOTF reference was lower than the MDD reference estimate by 1.4 and 2.6 percentage points in Russia and the USA, respectively (or in relative terms by one-third in Russia and the USA). The difference was much greater in children (about 4 percentage points in Russia and the USA)

**Table 2** Characteristics of the three study samples[a]

| Characteristics | China (n = 3014) Male | China Female | Russia (n = 6883) Male | Russia Female | USA (n = 6108) Male | USA Female |
|---|---|---|---|---|---|---|
| Children (6–9 y) | | | | | | |
| Sample size | 488 | 477 | 966 | 913 | 1096 | 1073 |
| Age (y) | 8.0 (1.2) | 8.1 (1.2) | 8.1 (1.1) | 8.2 (1.2) | 8.0 (1.2) | 8.0 (1.2) |
| Weight (kg) | 22.8 (5.7) | 22.1 (5.7) | 28.1 (7.5) | 27.7 (6.8) | 28.7 (8.3) | 28.6 (8.8) |
| Height (cm) | 119.6 (10.1) | 118.6 (10.3) | 127.1 (10.5) | 126.4 (10.9) | 128.2 (9.5) | 127.5 (9.5) |
| BMI (kg/m$^2$) | 15.9 (3.5) | 15.6 (3.4) | 17.4 (3.9) | 17.3 (4.0) | 17.2 (3.1) | 17.3 (3.5) |
| Adolescents (10–18 y) | | | | | | |
| Sample size | 1063 | 1016 | 2374 | 2630 | 1908 | 2031 |
| Age (y) | 14.3 (2.6) | 14.4 (2.6) | 14.7 (2.5) | 14.8 (2.7) | 14.1 (2.7) | 14.2 (2.6) |
| Weight (kg) | 42.2 (12.9) | 41.0 (10.2) | 51.5 (14.3) | 49.5 (11.9) | 56.1 (19.1) | 54.9 (16.2) |
| Height (cm) | 150.7 (15.3) | 147.7 (11.0) | 159.8 (16.2) | 155.9 (12.0) | 160.6 (14.8) | 156.7 (9.7) |
| BMI (kg/m$^2$) | 18.2 (3.0) | 18.6 (3.3) | 19.9 (3.5) | 20.1 (3.4) | 21.2 (4.8) | 22.1 (5.3) |

[a]Mean (s.d.). Sampling weights were not used for the USA.

**Table 3** The prevalence (%) of overweight (obesity was included) estimated using the IOTF and WHO (or MDD) references[a]

| | China (n = 3014) IOTF | WHO or MDD | Difference[b] | Russia (n = 6883) IOTF | WHO or MDD | Difference[b] | USA (n = 6108) IOTF | WHO or MDD | Difference[b] |
|---|---|---|---|---|---|---|---|---|---|
| All | 6.4 | 6.5 | −0.1 | 15.7 | 15.0 | 0.7 | 25.5 | 24.4 | 1.1 |
| Children (6–9 y) | | | | | | | | | |
| All | 10.5 | 11.9 | −1.4 | 26.6 | 29.4 | −2.8 | 22.0 | 24.6 | −2.6 |
| Male | 10.0 | 11.7 | −1.7 | 25.9 | 31.7 | −5.8 | 20.5 | 23.9 | −3.4 |
| Female | 11.0 | 12.1 | −1.1 | 27.4 | 27.1 | 0.3 | 23.6 | 25.3 | −1.7 |
| Adolescents (10–18 y) | | | | | | | | | |
| All | 4.5 | 4.0 | 0.5 | 11.7 | 9.6 | 2.1 | 27.1 | 24.4 | 2.7 |
| Male | 4.5 | 4.3 | 0.2 | 11.5 | 10.5 | 1.0 | 26.8 | 24.5 | 2.3 |
| Female | 4.5 | 3.7 | 0.8 | 11.7 | 8.9 | 2.8 | 27.5 | 24.3 | 3.2 |

[a]IOTF overweight reference, sex–age-specific BMI cut-offs, which correspond to BMI = 25 at age 18. WHO reference for adolescents (10–18 y), BMI 85th percentile; for children under age 10, we used the 'MDD reference', BMI 85th percentile.
[b]Difference = IOTF − WHO (or MDD).

than in adolescents (approximately 0.4 percentage point in Russia and 1.8 in the USA). Yet in general, kappa values still suggest good agreement, except for American children (kappa $<8$).

### Comparison of the IOTF and WHO references for obesity in children aged 6–9 y

We compared the IOTF (BMI cut-offs) and WHO (weight-for-height *Z*-score) obesity references among children aged 6–9 y and whose *Z*-scores could be calculated. We observed substantial differences in the estimates of obesity prevalence using these two references (Table 6). The WHO weight-for-height reference produced a much higher prevalence than the IOTF BMI reference. Among Russian children, the estimates of the prevalence of obesity based on the WHO reference were almost twice as high as those based on the IOTF reference (approximately 20 *vs* 10%). For the USA, the estimates according to the IOTF reference were only about two-thirds of those according to the WHO reference. Kappa was $<0.8$ for Russia and 0.8 for the USA.

A limitation of the WHO *Z*-score reference is worth mentioning. Weight-for-height *Z*-scores cannot be calculated for children whose height is outside the range set by the US Center for Disease Control and Prevention (CDC) when they developed the ANTHRO software for computing *Z*-scores based on the WHO/NCHS reference. For example, height for girls under 10 must be $\geq 55$ cm and $\leq 137$ cm; and height for boys under 12 should be within a range of 55–145 cm. These restrictions may limit the usefulness of this reference. For instance, 180 of the 1073 American girls from the NHANES III sample (16.8%) we examined had a height greater than 137 cm; and 4.4% (48/1096) of the American boys had a height greater than 145 cm. Tables 5 and 6 indicate that one would overestimate the prevalence of obesity in Russia if using WHO *Z*-score reference, but underestimate the problem in the USA due to the exclusion of some children whose height did not fall into the ranges required by the ANTHRO software. In other words, it was more likely that *Z*-scores could not be calculated for obese Russian children (classified using the IOTF BMI reference) than for non-obese children, while for the USA sample it was the opposite. This is likely to be due to the differences in height and the BMI–height associations between American and Russian children. Almost all excluded American children were excluded because their height was greater than the upper boundary required by the ANTHRO software, while many Russian children were excluded because they were too short. Meanwhile, there was a positive correlation between BMI and height for American children (0.43 for boys and 0.46 for girls), but a negative correlation for Russia ($-0.22$ for boys and $-0.23$ for girls).

**Table 4** Agreement between the IOTF and WHO (or MDD) references for overweight (obesity was included); kappa coefficient[a,b]

| | *China* | *Russia* | *USA* |
|---|---|---|---|
| All | 0.93 | 0.90 | 0.92 |
| Children (6–9 y) | | | |
| All | 0.92 | 0.90 | 0.90 |
| Male | 0.92 | 0.86 | 0.90 |
| Female | 0.92 | 0.95 | 0.90 |
| Adolescents (10–18 y) | | | |
| All | 0.94 | 0.88 | 0.92 |
| Male | 0.98 | 0.92 | 0.93 |
| Female | 0.90 | 0.84 | 0.92 |

[a]IOTF overweight reference, sex–age-specific BMI cut-offs, which correspond to BMI = 25 at age 18. WHO reference for adolescents (10–18 y), BMI 85th percentile; for children under age 10, we used the 'MDD reference', BMI 85th percentile.
[b]Kappa = 1 when the agreement between the two references is perfect; kappa $>0.8$ indicates an excellent agreement.

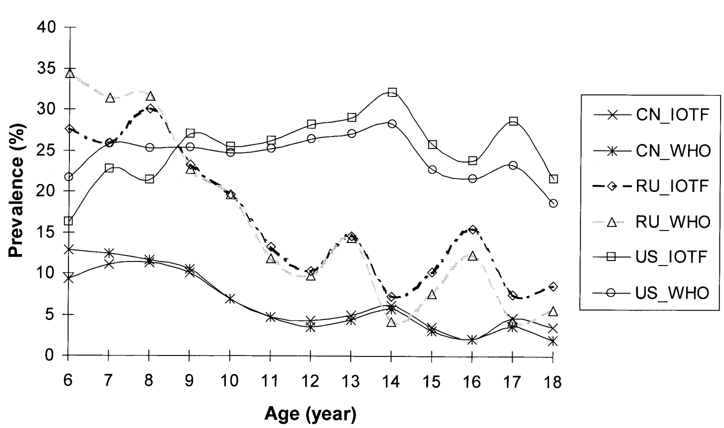


**Figure 2** Estimates of overweight prevalence (%) by age using the IOTF and WHO (MDD) references. CN, China; RU, Russia; US, the United States. IOTF reference: sex–age-specific BMI cut-offs that correspond to BMI = 25 at age 18. WHO reference: for adolescents aged 10–18, sex–age-specific BMI 85th percentile from US NHANES I data; for children under age 10, we also used the 85th BMI percentile ('MDD reference'), and it was called 'WHO reference' for simplicity.

**Table 5** Comparison of the IOTF and MDD obesity references for children and adolescents aged 6–18[a]

| | Prevalence of obesity (%)[b] | | | |
|---|---|---|---|---|
| | *IOTF* | *MDD* | *Difference*[c] | *Kappa* |
| *Russia* (n = *6883*) | | | | |
| *All* | 4.2 | 5.6 | −1.4 | 0.84 |
| *Children (6–9 y)* | | | | |
| All | 10.3 | 14.4 | −4.1 | 0.81 |
| Male | 9.5 | 13.2 | −3.7 | 0.83 |
| Female | 11.2 | 15.9 | −4.7 | 0.80 |
| *Adolescents (10–18 y)* | | | | |
| All | 1.9 | 2.3 | −0.4 | 0.89 |
| Male | 2.4 | 3.1 | −0.7 | 0.88 |
| Female | 1.3 | 1.6 | −0.3 | 0.91 |
| *The United States* (n = *6108*) | | | | |
| *All* | 7.8 | 10.4 | −2.6 | 0.84 |
| *Children (6–9 y)* | | | | |
| All | 8.6 | 13 | −4.4 | 0.77 |
| Male | 8.2 | 11.4 | −3.2 | 0.82 |
| Female | 9.1 | 14.8 | −5.7 | 0.73 |
| *Adolescents (10–18 y)* | | | | |
| All | 7.4 | 9.4 | −1.8 | 0.88 |
| Male | 7.2 | 9.7 | −2.5 | 0.84 |
| Female | 7.7 | 8.7 | −1 | 0.94 |

[a]IOTF obesity reference, sex–age-specific BMI cut-offs, which correspond to BMI = 30 at age 18; MDD reference, BMI 95th percentile. This comparison was not conducted for China, because the prevalence of obesity was very low.
[b]Kappa = 1 when the agreement between the two references is perfect; kappa > 0.8 indicates an excellent agreement.
[c] Difference = IOTF − MDD.

**Table 6** Comparison of the IOTF (BMI cut-offs) and WHO (weight-for-height *Z*-score) obesity references for children aged 6–9[a]

| | Prevalence of obesity (%)[b] | | | |
|---|---|---|---|---|
| | *IOTF* | *WHO* | *Difference*[c] | *Kappa* |
| *Russia* | | | | |
| All (*n* = 1678) | 11.1 | 20.5 | −9.4 | 0.65 |
| Male (*n* = 918) | 10.0 | 21.4 | −11.4 | 0.58 |
| Female (*n* = 760) | 12.4 | 19.5 | −7.1 | 0.74 |
| *The United States* | | | | |
| All (*n* = 1941) | 6.8 | 9.5 | −2.7 | 0.80 |
| Male (*n* = 1048) | 7.6 | 10.8 | −3.2 | 0.80 |
| Female (*n* = 893) | 5.8 | 7.9 | −2.1 | 0.80 |

[a]IOTF obesity reference, sex–age-specific BMI cut-offs, which correspond to BMI = 30 at age 18. WHO obesity reference, weight-for-height *Z*-score > 2. *Z*-scores could only be calculated for children whose height was between 55 and 137 cm for girls, and 55 and 145 cm for boys using the ANTHRO software. Thus, the sample sizes were different from those in previous tables.
[b]Kappa = 1 when the agreement between the two references is perfect; kappa > 0.8 indicates an excellent agreement.
[c]Difference = IOTF − WHO.

## Discussion

Our results show that the IOTF reference (BMI cut-offs that correspond to 18 at age 18) and the WHO and MDD reference (the 85th BMI percentile from the US NHANES I data) produce similar estimates for the overall combined prevalence of overweight and obesity in the three samples from China, Russia and the USA. The difference in the estimates of the overall prevalence by different references was small (0.1 percentage point in China, 0.7 in Russia and 1.1 in the USA). This suggests that findings of overall overweight prevalence based on the IOTF reference and the US 85th BMI percentile are comparable. Compared to the IOTF reference, the MDD reference gives slightly higher prevalence estimates of overweight among children, and the WHO reference produces slightly lower prevalence estimates among adolescents, but in general the differences are small. The difference in the prevalence of overweight estimated using these references is likely to be influenced by the BMI distribution in a study population. The absolute difference in the estimates according to different references is likely to be greater when overweight is more prevalent. For example, as the prevalence of overweight among adolescents increased from approximately 4–25% among our Chinese, Russian and USA samples, the difference increased from 0.5 to 2.7 percentage points. Most recently, Flegal *et al* (2001) compared the IOTF and MDD references and the new USA CDC Growth Charts (BMI percentiles) with USA data. To our knowledge, the present study is the first attempt of using data from different countries to systematically compare the references recommended by the WHO and IOTF for international use (Cole *et al*, 2000; WHO, 1995).

Another important finding is that the prevalence of overweight was much lower among adolescents (10–18 y) than children (6–9 y) in China and Russia, but the prevalence was similar in the USA. We suspect that the age-difference may be due to the fact that these references are more sensitive in identifying overweight children than overweight adolescents in low and middle-income countries for two possible reasons (if assuming a gold standard of overweight exists). First, due to different growth and development patterns among populations (Eveleth & Tanner, 1990; Falkner & Tanner, 1986), BMI–age relationship in developing countries such as China may be different from that in developed countries and the WHO and IOTF reference populations. For example, in a 6 y follow-up study conducted among Chinese children, using the IOTF BMI cut-off points we found that overweight prevalence decreased dramatically as children became adolescents although several other studies from China based on local references suggest a rise of obesity (Wang *et al*, 2000a,b; Ye & Sun, 1997). There is no evidence suggesting that the population's living standards have declined during this period (CNBS, 1999). In addition, although a large body of literature shows that, in general, about one-third of obese children and one-half of adolescents in the USA and many other industrialized countries remained obese as adults (Power *et al*, 1997; Serdula *et al*, 1993), using the IOTF and WHO overweight references, we and Mo-suwan *et al* found that only approximately 10% of overweight children remained overweight as adolescents 5–

6 y later (Mo-suwan *et al*, 2000; Wang *et al*, 2000a,b). We suspect that at least part of the remarked difference is due to a lower sensitivity of these two references to identify overweight individuals during adolescence than childhood in developing countries.

Second, children and adolescents from low and middle-income countries mature later than the WHO and IOTF reference populations (Eveleth & Tanner, 1990; Falkner & Tanner, 1986; Morabia, 1998). Taking menarche age in girls as an example, our previous study found that the median age at menarche, a good indicator of maturation rates across populations recommended by the WHO (1995), was 12.8 y in US NHANES I girls, 12.6 in US NHANES III girls, 13.7 in Chinese girls, and 13.3 in Russian girls (Wang & Adair, 2001; Godina *et al*, 1995). Increasing evidence suggests that maturation influences adiposity and it may also have a long-term effect on the development of obesity (Beunen *et al*, 1994; Daniels *et al*, 1997; Morrison *et al*, 1994; Van Lenthe *et al*, 1996). It is suggested that maturation should be considered whenever possible (Himes, 1999; Wang & Adair, 2001; WHO, 1995). However, neither the WHO committee nor the IOTF has provided practical means to address issues related to maturation differences when assessing the prevalence of overweight and obesity, although the WHO committee has recommended maturity adjustment for interpretation of population means of anthropometric measures (WHO, 1995). Our previous study shows that adjusting for maturation difference between the study and the WHO reference populations can increase the estimates of overweight prevalence by about one-quarter to one-third (in relative terms) in Chinese and Russian adolescent girls, or by about 2 percentage points in absolute terms (Wang & Adair, 2001). Future research is needed to explain the phenomena we have observed. For example, how much of the age-difference in overweight prevalence between children and adolescents in China and Russia is due to socioeconomic and behavioral factors, and how much is due to possible misclassification by these international references? This research will provide important insights concerning the validity of these references for international use.

In addition, it is also possible that the remarked age-difference in overweight among children and adolescents across countries we observed may be related to some underlying socioeconomic and behavioral factors that differ among the three countries (ESCAP, 1998; CNBS, 1999; Jing, 2000; World Bank, 1999; Zohoori *et al*, 1998). For example, in China and Russia, children may have a higher energy diet and be less active than adolescents; as a result, they are at a higher risk for overweight. In other words, the difference may be related to a cohort effect or secular trend. As many Chinese families, particularly in urban areas, only have one child, the only child enjoys overwhelming care and family resources provided by their parents and grandparents at young ages (Jing, 2000). It is possible that these children may change their eating and physical activity patterns remarkably when they grow older, although little research has been conducted to test this hypothesis. Second, stunting at young ages is suggested as a risk factor for development of obesity (Popkin *et al*, 1996). It is possible that the high prevalence of stunting among children of young ages, particularly in China (Ge, 1999), may be related to the phenomenon we observed. Finally, changes in nutritional status might be more sensitive to food shortage during adolescence than during childhood. In the early 1990s, Russia experienced remarked socioeconomic difficulties (World Bank, 1999; Zohoori *et al*, 1998). Further research is needed to test the above hypotheses.

Among children and adolescent, we compared the IOTF obesity reference (BMI cut-offs that correspond to BMI of 30 at age 18) and the MDD reference (the US BMI 95th percentile). The overall prevalence estimated using the MDD reference is higher than that of the IOTF reference. The difference among adolescents is small, only 0.4 – 1.8 percentage points. However, the difference is much greater among children. The prevalence according to the IOTF and MDD references is 10.3 *vs* 14.4% for Russia and 8.6 *vs* 13.0% for the USA, respectively. These clearly suggest that obesity prevalence estimated using these two references is not comparable among children.

In addition, for children aged 6 – 9, we compared the IOTF (BMI cut-offs) and WHO (weight-for-height *Z*-score) obesity references. The prevalence estimates of obesity differed substantially. This is not a surprise because of the differences between the two references. The fact that weight-for-height *Z*-scores cannot be calculated for children of ‘extreme’ height limits the usefulness of the WHO *Z*-score reference. Thus, the IOTF reference seems to be superior. Also, the simplicity of using BMI cut-offs for all children aged 2 – 18 y and for defining both overweight and obesity makes the IOTF reference easier for use in population-based studies and in monitoring efforts, especially in developing countries.

Finally, although these references are useful for making meaningful comparisons between studies and countries and for monitoring the global obesity epidemic, no conclusive evidence has emerged concerning the validity of these references in developing countries where children and adolescents have substantially lower BMIs and mature much later than the reference populations. It has been argued that population-specific standards should be used due to the differences in relationships between BMI and body fat, and between BMI and risks for diseases (Daniels *et al*, 1997; Deurenberg *et al*, 1998). Currently little is known about whether children from developing countries are at the same risk for subsequent obesity-related diseases when they are at the upper extremes of BMI as are overweight individuals from wealthy societies (WHO, 1995). In fact, both the IOTF and WHO references are statistical-definition-based references, but not based on evidence of long-term health risks associated with elevated BMI levels in childhood and adolescence. The WHO committee is aware that the BMI cut-offs derived from the USA data may not be valid in developing countries such as India where BMI distributions during adolescence are much lower than the USA population (WHO, 1995). Cole *et al* (2000) also recognize that the populations made up of their IOTF reference population are less than ideal, 'which probably reflects Western populations adequately but lacks representations from other parts of the world'. Recently a number of scholars have raised their concerns regarding the IOTF reference for international use (Wang *et al*, 2000). Moreover, even for adults there are concerns about using universal BMI cut-offs to classify overweight and obesity. For example, in a recent document coordinated by the International Diabetes Institute and co-sponsored jointly by the WHO Regional Office for the Western Pacific, the International Association for the Study of Obesity and the IOTF, different criteria for overweight (BMI = 23) and obesity (BMI = 25) are recommended for adults within the Asia-Pacific region than the current WHO BMI cut-offs of 25 and 30 (Inoue *et al*, 2000). Recently, BMI cut-offs of 24 for overweight and 28 for obesity have been recommended in China (Chen Chun-ming, personal communication, 2001). These lower cut-offs were recommended because emerging evidence suggests that the increased risks associated with obesity occur at lower BMI values in Asians (Inoue *et al*, 2000). In addition, as an indirect measure of body fatness, BMI has several well-known limitations in measurement of obesity (Himes, 1991). The large age-difference in the estimates of overweight prevalence between children and adolescents we observed between developing and developed countries and the remarked difference in the estimates of obesity prevalence call for further research to examine the validity of these references for international use, particularly in developing countries.

In conclusion, a good international reference to define child and adolescent overweight and obesity is useful for making meaningful comparisons across studies and populations, and for monitoring the global obesity epidemic. Overall the WHO and IOTF references produce similar estimates of combined prevalence of overweight and obesity, but the WHO reference generates a slightly higher estimate in children and a lower estimate in adolescents than the IOTF reference. One should be aware of the limitations of each reference and be cautious when comparing results based on different references. Considering the limitations and unique strengths of the WHO and IOTF references, it is premature to recommend one over another before more evidence emerges from well-designed studies for children and adolescents in different parts of the world. Nevertheless, if one has to make a choice, considering the simplicity and linkage with BMI cut-offs used in adults, the IOTF reference seems to be superior. However, efforts should be made to eliminate potential misconceptions. The IOTF reference has been developed recently and is based on multinational data, and as a result it may be easily accepted by health professionals and the public as a 'justified' international reference without acknowledging its limitations. Further, since the IOTF reference population consists of several diverse populations, which have very different BMI distributions, growth and sexual maturation patterns, body features (eg trunk–leg ratio), and social economic characteristics, it will be difficult for one to address the differences between the reference and his study populations and the related potential influence on the results. Efforts are still needed to develop better justified references for international use.

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