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Population-based waist circumference reference values in Japanese children (0–6 years): comparisons with Dutch, Swedish and Turkish preschool children

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Abstract

Background: During 1978–1981 the Japanese Standards Association conducted a national survey to collect 64 distinct body measurements for Japanese children and adults. During 1978–1981, the prevalence of childhood obesity was relatively low yet the population was well nourished in Japanese children. The aim of this study is to construct waist circumference and waist circumference to stature ratio reference centile curves for Japanese preschool children.

Methods: We utilized 1978–1981 national survey data on body sizes. There are 4937 boys and 4758 girls age 0–6 years for waist circumference measurements. Waist circumference was measured at the level of the umbilicus. Using LMS method, centile curves were constructed for waist circumference and waist circumference to stature ratio. These reference values were compared with those of Dutch, Swedish and Turkish children.

Results: Centile reference curves were made for clinical and epidemiological use. Japanese children had smaller waist circumference centile values as compared to waist circumference measured at the midpoint of the lowest rib cage and the iliac crest of Dutch, Swedish and Turkish children. However, Japanese children had comparable waist circumference to stature ratio centile values to those of Dutch and Turkish children.

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Conclusions: This study presents the first age-, sex-, and ethnicity-specific reference values for waist circumference and waist circumference to stature ratio in Japanese preschool children.

Keywords: body proportion; growth curves; Japanese Standards Association; LMS method; nationally representative data.

Introduction

Various measurements are used to define and calculate overweight and obesity in children. The body mass index (BMI) is the most widely used tool to assess overweight and obesity. However, this index has limitations when used in children. BMI correlates not only with fat mass but also with fat-free mass; while it has high specificity, it has low sensitivity [1]. Finally, BMI provides no indication of body fat distribution and obesity-related morbidity is more strongly attributed to abdominal obesity rather than general obesity in children [2, 3].

Waist circumference (WC) has been shown to be a highly sensitive and specific marker of abdominal fat accumulation in children. While it cannot distinguish between subcutaneous and visceral fat [4], WC may be a better indicator of obesity-related disease risk. Children who are younger than 6 years have been excluded when metabolic syndrome was defined because of insufficient data for this age-group. We, therefore, tried to establish WC reference centile curves for Japanese children (0–6 years of age). The International Diabetes Federation (IDF) proposed to use the 90th centile as a cut-off for WC [5].

The Japanese Standards Association 1978–1981 survey of body segments offers a unique opportunity to utilize high quality nationally representative data in Japanese children [6]. We have previously proposed the 1978–1981 population as baseline year of references for BMI, since either undernutrition in poverty or unhealthy dieting in affluent society was relatively rare in 1978–1981, as supported by several national surveys on nutrition and youth behavior [7]. If we set forth cut-offs of BMI >95th centile of

the 1978–1981 reference population as a measure of overweight, this implies that the prevalence of overweight is 5% by definition in the 1978–1981 survey population, and is 11.0% in boys and 8.5% in girls, respectively, in the 1992–1994 population [8]. From 1978–1981 and 1992–1994 Japanese Standards Association and Research Institute of Human Engineering for Quality Life, as sponsored by Ministry of International Trade and Industry, conducted nationally representative survey on various anthropometric measurements of Japanese children and adults. For the third time, the 2004–2006 national survey was performed only for adults, allegedly due to budgetary limitations. WC was measured in children in the 1978–1981 and 1992–1994 surveys. Comparison between the 1978–1981 and 1992–1994 WC charts showed a large increase in WC over time.

There is no standardized method of measurement for WC; and several different methods of measurement are currently in use, leading to potential confusion. There are four commonly recommended WC measurement sites along the body and all sites were not equivalently associated with metabolic risk [9]. However, Harrington et al. concluded that WC measurement site did not affect relationships with visceral adiposity and cardiometabolic risk factors in children [10]. Measurement at the umbilical level was adopted in this study, since the measurements were primarily for garments under 0–6 year olds. The previous studies (study subjects 6–18 years old) [11, 12] and present study (study subjects 0–6 years old) were combined to complete national reference values of WC and waist circumference to stature ratio (WC/S), making successive data tracking feasible. The measurement sites of WC (6–18 years of age) were different between sexes: for boys, WC was measured at the level of the top of the iliac crest (waist circumference 2: WC2); and for girls, WC was measured at the level of maximum waist narrowing (waist circumference 1: WC1).

There are only limited data on WC in infants and preschoolers covering 0–6 years of age. Those include Dutch, Swedish and Turkish studies performed in 1996–1997, 2006, and 2009–2010, respectively [13–15]. For Dutch, Swedish and Turkish infants and preschoolers, WC was measured at the midpoint of the lowest rib cage and the iliac crest (waist circumference 3: WC3). Although the WC measurement sites differ among investigators, each reflects abdominal fat accumulation well [10].

Subjects and methods

We conducted a secondary analysis of previously collected nationally representative data by the Japanese Standards Association from 1978–1981 as sponsored by the Japanese

Ministry of International Trade and Industry [6]. The analyses were based on WC and waist circumference to stature ratio (WC/S) for 4937 boys and 4758 girls, 0–6 years of age; measurements were conducted by trained personnel. Stature was measured to the nearest 0.1 cm. WC was measured, using a tape measure placed around the waist at the level of the umbilicus (waist circumference measured at the level of the umbilicus: WCu). During the measurement, 0–1 year olds were placed in the supine position and 2–7 year olds in the standing position. Holding a subject in arms would give erroneously large value of WC, therefore, this was carefully avoided.

Reference centile curves for WCu and WCu/S were constructed using the LMS method [16–18]. The LMS method summarizes the centiles by three smooth curves representing skewness (L curve), the median (M curve) and coefficient of variation (S curve). This assumes that the distribution of the measurements, as summarized by the median, coefficient of variation (CV) and degree of skewness, changes smoothly with age. The LMS transformation equation is: $X = M(1 + LSZ)^{1/L}$, where X is the physical measurement and Z is the z -score that corresponds to the centile.

This study constructed the WCu and WCu/S reference curves for younger children (0–6 years of age) along with WC (boys, WC2; girls, WC1) and WC/S (boys, WC2/S; girls, WC1/S) reference curves for older children (6–18 years of age) [11,12]. Data of each subject was obtained from the same nationally representative survey by the Japanese Standards Association in 1978–1981. WC and WC/S reference data of children (6–18 years of age) were calculated from L, M and S values reported in each reference paper [11, 12].

The WCu and WCu/S reference data of Japanese younger children (0–6 years of age) were compared with the WC3 and WC3/S reference data of Dutch, Swedish and Turkish infants and preschoolers [13–15]. The 50th centile values of WC3/S for Dutch preschool children were calculated from 0 standard deviation (SD) values of WC3 reference/mean values of stature [13, 19]. The 50th centile values of WC3/S for Swedish preschool children were the median values of WC3/S reported in the reference paper [14]. The 50th centile values of WC3/S for Turkish preschool children were calculated from 50th centile values of WC3 reference/50th centile values of stature reference [15, 20].

The Institutional Review Board of Keio University School of Medicine approved the study.

Results

Table 1 shows number of subjects, mean and SD for WCu and WCu/S. Since the number of subjects under 0.25 years

Table 1: Number of subjects, mean and SD for WCu and WCu/S for Japanese preschool children (0–6 years).

Age range, years	n		WCu, cm, mean, SD		WCu/S mean, SD	
	Boys	Girls	Boys	Girls	Boys	Girls
0–0.25	46	41	38.7 (3.4)	37.2 (2.7)	0.66 (0.04)	0.65 (0.04)
0.25–0.50	140	127	41.1 (2.9)	40.1 (2.4)	0.64 (0.04)	0.65 (0.04)
0.50–0.75	210	214	41.9 (2.5)	41.0 (2.6)	0.61 (0.04)	0.61 (0.04)
0.75–1.00	208	207	42.5 (2.7)	41.5 (2.5)	0.59 (0.04)	0.59 (0.04)
1.00–1.25	149	138	43.4 (2.6)	41.9 (2.3)	0.57 (0.03)	0.56 (0.03)
1.25–1.50	109	113	44.4 (2.4)	44.1 (2.4)	0.56 (0.03)	0.57 (0.03)
1.50–1.75	124	114	45.4 (2.7)	45.5 (2.6)	0.56 (0.03)	0.57 (0.03)
1.75–2.00	110	109	46.3 (2.7)	45.4 (2.6)	0.55 (0.03)	0.55 (0.03)
2.0–2.5	425	407	46.9 (2.8)	46.5 (2.6)	0.54 (0.03)	0.55 (0.03)
2.5–3.0	442	433	47.3 (2.3)	47.2 (2.7)	0.52 (0.03)	0.53 (0.03)
3.0–3.5	505	454	48.2 (2.5)	47.8 (2.8)	0.51 (0.03)	0.51 (0.03)
3.5–4.0	509	492	48.4 (2.6)	48.9 (3.0)	0.50 (0.02)	0.50 (0.03)
4.0–4.5	385	352	48.9 (2.6)	49.2 (3.1)	0.48 (0.03)	0.49 (0.03)
4.5–5.0	361	387	49.7 (2.9)	49.5 (3.3)	0.48 (0.03)	0.48 (0.03)
5.0–5.5	391	357	50.1 (3.1)	50.0 (3.4)	0.47 (0.03)	0.47 (0.03)
5.5–6.0	417	413	51.2 (3.7)	50.7 (3.3)	0.46 (0.03)	0.46 (0.03)
6.0–6.5	406	400	51.4 (3.6)	51.1 (4.1)	0.45 (0.03)	0.45 (0.03)

of age and over 6.25 years of age were less than 50 in both sexes, we excluded these age groups and final data used is based on measurements for 4855 boys and 4688 girls.

Table 2 shows the Box-Cox power L, the adjusted mean M, the coefficient variation S values for WCu and WCu/S by age range and sex for Japanese preschool children. Figure 1 shows WCu-for-age, 0–6 years of age, and WC-for-age, 6–18 years of age [11], the 3rd, 10th, 25th, 50th, 75th, 90th, and 97th centile curves. Figure 2 shows WCu/S-for-age, 0–6 years of age, and WC/S-for-age, 6–18 years of age [12], the 3rd, 10th, 25th, 50th, 75th, 90th, and 97th centile curves. The reference curves of WCu-for-age and WCu/S-for-age were similar in boys and girls aged 0–6 years of age. There were apparent differences between WCu and WC1, and between WCu/S and WC1/S at age 6 years in girls, with WCu and WCu/S being significantly greater than WC1 and WC1/S, respectively. These combined national reference values of WC and WC/S make successive data tracking feasible.

Figure 3 presents WCu 50th centile curve for Japanese preschool children in comparison with WC3 50th centile curves for Dutch, Swedish and Turkish preschool children. Japanese preschool children had smaller WCu centile values as compared to WC3 of Dutch, Swedish and Turkish preschool children. Figure 4 presents WCu/S 50th centile curve for Japanese preschool children in comparison with WC3/S 50th centile curves for Dutch, Swedish and Turkish preschool children. Japanese preschool children had comparable WCu/S centile values to WC3/S of Dutch and Turkish preschool children.

Discussion

1978–1981 as baseline year

This study presents the first centile reference curves for WCu and WCu/S for Japanese children 0–6 years of age, based on the 1978–1981 national survey data. Using the same 1978–1981 survey data, we previously determined the centile reference curves for BMI in Japanese children 2–18 years of age [21, 22] and for WC and WC/S in Japanese children 6–18 years of age [11, 12].

Thus, 1978–1981 is a critical period for anthropometric data of Japanese children: The 1978–1981 survey generated 64 distinct body measurements and proportions which could be used for possible future studies [6]. The BMI centile reference curves were prepared using 1978–1981 data as baseline values to assess population trend in weight. During 1978–1981, the prevalence of childhood obesity was relatively low yet the population was well nourished [21, 22].

According to the National Growth Survey on Preschool Children, the mean stature and the mean weight remained stable from 1980–2010 [23]. Comparing BMI between the 1978–1981 reference value [21,22] and the 2000 reference value [24, 25] for school-age children, the 2000 reference values were much larger than the 1978–1981 reference values; however, for preschool-age children, the 2000 reference values were the same as or slightly smaller than the 1978–1981 reference values [26]. Therefore, we believe that the 1978–1981 reference data is usable and

Table 2: L, M, S values for WCU and WCU/S for Japanese preschool children (0–6 years).

Age, years	WCU						WCU/S					
	Boys			Girls			Boys			Girls		
	L	M	S	L	M	S	L	M	S	L	M	S
0.25	−0.76	40.7	0.065	−1.14	39.8	0.062	1.68	0.65	0.059	−0.75	0.65	0.064
0.50	−0.76	41.4	0.063	−0.93	40.6	0.061	0.76	0.62	0.061	−0.56	0.62	0.062
0.75	−0.76	42.3	0.061	−0.70	41.2	0.059	0.21	0.59	0.060	−0.40	0.59	0.060
1.00	−0.78	43.1	0.059	−0.47	42.0	0.058	0.00	0.58	0.059	−0.32	0.57	0.057
1.25	−0.84	44.0	0.058	−0.27	43.3	0.057	−0.06	0.56	0.057	−0.29	0.57	0.056
1.50	−0.92	44.9	0.056	−0.18	44.6	0.056	−0.08	0.56	0.056	−0.29	0.56	0.055
1.75	−1.02	45.6	0.055	−0.20	45.4	0.056	−0.09	0.55	0.055	−0.30	0.56	0.054
2.0	−1.13	46.2	0.054	−0.30	46.0	0.056	−0.10	0.55	0.054	−0.33	0.55	0.054
2.5	−1.35	47.1	0.053	−0.62	46.9	0.057	−0.16	0.53	0.051	−0.47	0.53	0.054
3.0	−1.54	47.7	0.052	−0.97	47.5	0.058	−0.31	0.51	0.050	−0.75	0.52	0.054
3.5	−1.71	48.1	0.053	−1.37	48.2	0.059	−0.55	0.50	0.050	−1.04	0.50	0.055
4.0	−1.88	48.6	0.054	−1.76	48.8	0.061	−0.89	0.49	0.051	−1.33	0.49	0.055
4.5	−2.09	49.1	0.055	−2.01	49.1	0.062	−1.36	0.48	0.052	−1.64	0.48	0.055
5.0	−2.32	49.6	0.057	−2.27	49.5	0.063	−1.87	0.47	0.053	−1.91	0.47	0.057
5.5	−2.59	50.3	0.060	−2.62	50.0	0.065	−2.36	0.46	0.055	−2.11	0.46	0.059
6.0	−2.88	50.9	0.063	−2.90	50.4	0.067	−2.84	0.45	0.056	−2.37	0.45	0.062
6.25	−3.01	51.2	0.064	−2.99	50.6	0.067	−3.15	0.45	0.057	−2.51	0.45	0.063

Figure 1: WC-for-age, 0–6 years of age and WC-for-age, 6–18 years of age for Japanese children. The 97th, 90th, 75th, 50th, 25th, 10th and 3rd centile curves are shown.

Figure 2: WC/S-for-age, 0–6 years of age and WC/S-for-age, 6–18 years of age for Japanese children. The 97th, 90th, 75th, 50th, 25th, 10th and 3rd centile curves are shown.

Figure 3: WC 50th centile curve for Japanese preschool children in comparison of WC 50th centile curves for Dutch, Swedish and Turkish preschool children.

Figure 4: WC/S 50th centile curve for Japanese preschool children in comparison of WC/S 50th centile curves for Dutch, Swedish and Turkish preschool children.

appropriate for preschool age children in recent years. The reference values developed in this study could be used to evaluate longitudinal WC and WC/S of an individual throughout childhood. The reference values for 6–18 years of age were previously reported based on 1978–1981 survey [11, 12] (Figures 1 and 2). However, it is necessary to measure two types of WC (boys: WCu and WC2, girls: WCu and WC1) at 6 years of age, since the methods of measurement for WC are different between this study and the previous study [11, 12].

Foreign studies

There are only limited number of publications on WC in young infants and preschoolers covering 0–6 years of age: Dutch study (0–21 years) in 1996–1997 data [13], Swedish study (0–5 years) on 2006 data [14], and Turkish study (0–6 years) on 2009–2010 data [15]. In contrast, Japanese study is based on data collected in 1978–1981. For all the foreign

studies, WC was measured at the midpoint of the lowest rib cage and the iliac crest (WC3). The Dutch reference values of WC3 were based on data from 14500 children and adults of Dutch origin aged 0–21 years in the Fourth Dutch Growth Study in 1996–1997. The Swedish reference values of WC3 and WC3/S were based on data from 4502 children, 0–5 years of age, living in County of Holland in the south-west of Sweden in 2006. The Turkish reference values of WC3 were based on data from 2947 children, 0–6 years of age, living in Kayseri, one of the five great cities in 2009–2010. Dutch reference and Turkish reference were constructed using LMS method, and Swedish reference was constructed using the Box-Cox-power-exponential distribution. The present study utilized nationally representative WCu data on 9543 Japanese children, age 0–6 years, by LMS method.

Among the four populations studied, Japanese preschool children had the smallest WC (Figure 3). In children, a limited number of studies have documented the difference in absolute WC measurements between WCu and WC3,

showing that WCu is larger than or not significantly different from WC3. Harrington et al. found that WCu yield higher values than WC3 in White (males and females) and African American females, and do not significantly differ from WC3 in African American males, in children aged 5–18 years [10]. Yang and Wang compared WC measurements between WC measured at 1 cm above the umbilicus and WC3 in Chinese children aged 9–19 years, and found that WC measured at 1 cm above the umbilicus yield higher values than WC3 in males, and do not significantly differ from WC3 in females [27]. Therefore, even considering the difference in the measurement of WC, Japanese preschool children might have smaller WC than the three other countries. However, for preschoolers, as far as we know, the differences are not documented.

The differences of WC between Japanese and Dutch and Turkish preschool children disappear, if WC/S is compared. However, the differences of WC between Japanese and Swedish preschool children persist when adjusted for stature (Figure 4). The results in our study are consistent with a study of a sample of Chinese children. Zong et al. constructed the reference values of WC and WC/S for Chinese children aged 3–7 years and compared them with the reference values for children in other countries, including those in the Netherlands [13] and in Sweden [14]. They reported that the median WC and WC/S curves in Chinese children were generally lower than those in comparison countries [28].

WC/S, as expected, is a useful index in comparative study involving various body size groups. The reason for uniquely high WC/S in Swedish preschool children remains unknown. The factors that contribute to the observed differences are likely to be heterogeneous in nature, including the differences of body size of each population, benchmark in measurement, the year of study (secular trends), small sample size of young infants (edge effect) and the smoothing methods used for the references. Roswall et al. discussed that the difference in WC between Swedish and Dutch could be due to the fact that there was a 10 years difference between these studies, with a secular trend interfering, or it could be due to genuine differences between the two populations [14]. They also discussed that the data from German preschool children aged 3–5 years [29] are identical to their data, even though some minor differences in WC but not in WC/S were found exclusively in females.

Diagnosis of obesity in preschool children

Diagnosis of obesity has not been established in preschool children due to the lack of sufficient data. There are several

reports on the significance of measuring WC in preschool children. Taylor et al. showed WC performing well as an indicator of high trunk fat mass in preschool children [30]. It has also been reported that WC was independently associated with high blood pressure, in the overweight/obese preschool Chinese children [31]. These studies suggest that WC reflects abdominal fat and it cannot be denied that WC may be related to cardiovascular risks such as hypertension, even in preschool children. Therefore, at the moment, we propose that measurement and longitudinal evaluation of WC be performed for infants and preschoolers at the time of well-baby clinic visit.

The international WC cutoffs were developed to screen central obesity in children and adolescents aged 6–18 years, using the pooled data on WC of children and adolescents from eight countries in different regions (Bulgaria, China, Iran, Korea, Malaysia, Poland, Seychelles and Switzerland) [32]. The age- and sex-specific 90th centile WC cutoffs were calculated in children and adolescents with normal weight (excluding youth with obesity, overweight or underweight) by linking the centile with cardiovascular risk. The cut-off values of WC aged of 6 years (58.7 cm for boys and 57.9 cm for girls) correspond to 97th centile for boys and 96th centile for girls, respectively, in the WC reference values for Japanese preschool children in our study. These centile values may be useful in monitoring the growth of WC in Japanese preschool children.

Generally, the cut-offs of WC and WC/S are developed for early detection of abdominal obesity and its associated cardiovascular risk, but it is difficult to determine the cut-offs because preschool children have less disease related to abdominal obesity than school-aged children, adolescents and adults. Thus, further research might be necessary to develop the cut-offs of WC and WC/S for preschool children. Our study presented WC and WC/S centile reference values for Japanese preschool children which may be useful to monitor growth, as well as weight and BMI, and to evaluate abdominal fat distribution of Japanese preschool children.

‘Thin fat’ phenotype

The previous comparative studies showed that for the same BMI, age and gender, Asians had a higher body fat percentage [33]. Unfortunately, Japanese preschool children have no such data available. Asians in general tend to have a higher abdominal fat compared to Caucasians. Among Asians, Indians have the highest body fat percentage followed by Malays and Chinese. Krishnaveni et al. showed that South Indian babies have a muscle-thin but adipose

(‘thin-fat’) phenotype characterized by larger subscapular skin fold thickness. The phenotype persists in childhood [34]. They stated the phenotype may be the forerunner of a diabetogenic phenotype of south Asian adults. We anticipate that the present study about WC data for Japanese preschool children (0–6 years) will help to clarify the possibility of having the ‘thin-fat’ phenotype from the relationship between WC and BMI for Japanese children of Asian ethnicity.

Conclusions

This study presents for the first time reference values for WC and WC/S in Japanese preschool children (0–6 years). Tracking WC in early childhood may be the key to understanding the truncal fat adiposity.

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