Waist circumference percentiles for Singaporean children and adolescents aged 6-17 years

Swarup Mukherjee, Leong Hin Fong, Wong Xiao Xuan
Highlights

- Waist circumference is a strong predictor of metabolic risk in pediatric population
- South Asian children show greater propensity for abdominal obesity.
- Population specific cutoffs are important for population-specific screening.
- This is first working waist circumference percentile data for Singaporean children and adolescents.
- Using waist circumference cut-offs with BMI will increase the sensitivity for paediatric obesity screening.
- Cross-cultural comparisons support the need for population-specific data.
Abstract

Aim: Population-specific waist circumference (WC) percentiles are crucial for screening children at higher obesity-related metabolic risk. This study aimed to develop age- and gender-specific WC percentile curves for Singaporean children and adolescents.

Methods: 3029 participants (boys, 1506; girls, 1523) from different population strata of Singapore were recruited. Stature, weight and WC were measured and BMI calculated. Smoothed WC percentile curves and cutoffs for the 3rd, 5th, 10th, 25th, 50th, 75th, 85th, 90th, 95th, 97th were constructed using the Cole’s LMS method.

Results: WC and BMI increased with age in both sexes and boys had higher WC than girls at every age. Comparison of 50th and 90th percentiles with other populations showed distinct difference in WC curve pattern and values of Singaporean children.

Conclusions: We present the first working WC percentile curves and age- and gender-specific cutoffs of Singaporean children and adolescents. These cutoffs and curves can serve as valuable reference for screening and identify children at a higher metabolic risk, for international comparisons and to better understand secular trends in pediatric obesity.

Key words: Abdominal obesity, Asian, Pediatric population, Singaporean, Waist circumference percentiles
Introduction

Pediatric obesity is one of the most serious public health challenges of the 21st century and its prevalence is increasing at an alarming rate (1). Similar to the international trends, overweight and obesity rates have been rising in Singapore (2). Adult Singaporeans have a higher percentage body fat than Europeans (3), comparable coronary artery disease-related mortality rates to that in Australians and North Americans and higher than other Asian populations like Japan and Hong Kong (4). Notably the prevalence of obesity has increased 9-fold amongst the Primary 1 children (from 1.4% to 12.7%) and 7-fold amongst the Primary 6 children (from 2.2% to 15.9%) between 1976 to 2006 (5). Such trends make it imperative to adopt a simple, sensitive and specific anthropometric measurement as a tool to screen and identify children at a higher risk of obesity and its related metabolic risks. In Singapore, the percentage weight-for-height norms have been used to screen for childhood obesity since 1984 with 10 yearly revisions (6). Since 2010, BMI-for-age norms have been introduced in Singapore to categorize the children and adolescents into different weight categories.

Body Mass Index (BMI) has been widely used across various clinical and epidemiological contexts to measure obesity in both adults and children and the BMI cut-offs for public health action has been developed for both international and Asian pediatric populations (7). However, BMI does not indicate the pattern of fat distribution (8) and therefore may not be a strongly sensitive indicator of adiposity in children. It has been reported that central adiposity, specifically abdominal fatness carries a higher risk of metabolic complications (9) and BMI has low sensitivity to detect children with central adiposity that may be at a higher risk of obesity-related morbidities. Consequently, BMI by itself may not be an adequately specific and sensitive tool to detect children at a higher risk of metabolic syndrome (8).

Growing evidence suggests that abdominal fatness, as measured by waist circumference (WC) has stronger associations with the risks of metabolic syndrome (MS) and cardiovascular
diseases (CVD) than BMI. Abdominal fat in children aged 5-17 years is associated with CVD risk factors like high triglycerides and LDL cholesterol, low HDL cholesterol and high insulin levels (10). Moreover, WC in children correlates well with truncal adiposity as measured by dual-energy X-ray absorptiometry and is the indicator least affected by age, gender, ethnicity and overall fatness (11). While the conicity index, that evaluates WC in relation to height and weight is related to the atherogenic risk factors, it is not as accurate a measure of central adiposity as WC in children reflecting that ratios may not be appropriate for assessing obesity (11). This further reinforces the notion that WC as a surrogate marker of abdominal adiposity has a higher sensitivity to identify children at risk of adverse effects of obesity. A recent study in Singapore Chinese adults also reported that amongst blood pressure, WC and BMI, WC had the highest predictive utility and was the most accurate in identifying MS (12). Collectively the evidence supports that the prediction of childhood obesity-related health risk is significantly improved by the inclusion of WC in addition to the BMI percentiles. Therefore, considering the findings of increasing central fatness in children and the strength of correlation between WC and MS risk factors (10), the WC percentiles would be a practical addition to the BMI percentiles for screening and evaluation of obesity and its related risks in the pediatric population.

WC reference data have been developed for various pediatric populations over the last three decades (13-15). However, there are no published reference WC percentiles for the Singapore pediatric population. While secular trends indicate a rapid rise in overweight and obesity throughout the Asia-Pacific region (16), there is a dearth of reference data on WC in South East Asian children and adolescents with apparently just one published data on Malaysian children (15). While BMI cut-offs for public health action has been developed for both international and Asian pediatric populations (7), apparently there are no such reference cut-offs for WC. Moreover, it has been suggested that population-specific cutoff values may be more appropriate than the international values for use in population-specific screening programmes (6). Asian
populations have increased sensitivity to adiposity and its related risks compared to Caucasians and also seem to have an ethnic predisposition to MS (17). South Asian children show a greater propensity towards central fat distribution compared to the Caucasian children and consequently have a higher risk of T2DM (18). However, no such trends have been reported for the South East Asian children. As children from different countries differ in their rate of growth and fat distribution patterns, visceral adiposity is highly variable in children and is related to the ethnicity (19). Therefore, the various international reference values may not be generalizable to Singaporean adolescents. Consequently, the primary objective of this study was to develop the WC percentiles of Singaporean children aged 6.0-16.9 years and this paper presents the first set of working WC percentiles obtained from data collected from Singaporean children. We hypothesized that WC at 90th percentile would have a higher sensitivity than BMI and that the Singaporean paediatric population would show distinct WC percentile values and curve patterns compared to other populations.

**Material and Methods**

**Subjects**

3029 subjects (boys 1506, girls 1523) aged 6.0-16.99 years from a total of 12 primary and secondary Singapore Government-aided schools participated in the study. Stratified random sampling was used to select schools from the different zones of Singapore to provide a good representation in terms of broad geographical coverage, ethnic distribution and socio-economic diversity. Stratification was done based on the latest Singapore population distribution statistics for the below 15 year old residents (20) following which the list of schools in these strata were obtained from the School Information Service of the Ministry of Education Singapore (21). Six primary and secondary schools each were then randomly selected from the list of schools. Thereafter, the schools helped with randomly selecting 20 boys and girls each from each level of a primary school and 30 boys and girls each from each level of a secondary school.
Necessary approvals were obtained from the University’s Institutional Ethics Review Board, Ministry of Education Singapore and School Principals prior to the data collection. Parent consent and student assent were also sought beforehand. The study was conducted during 2014-15.

**Measurements**

All anthropometric measurements were performed by International Society for Advancement of Kinanthropometry (ISAK) Level 2 certified researchers. Stature was measured using a portable stadiometer (Charder HM-200P) to the nearest millimeter and weight was measured using a digital weighing scale (OMRON KaradaScan HBF-362) to the nearest 0.1 kilogram. Both the measurements were taken in light clothing and without shoes. All measurements were done between 8:30-11:30 AM. In accordance to the WHO method, WC was measured midway between the lowest rib margin and the upper border of iliac crest using a non-elastic flexible SECA anthropometric tape by a research team member of the same gender. During the WC measurement the subjects stood upright facing the researcher with weight equally distributed on both legs. The tape was placed snugly in horizontal position around the waist and the reading of the WC was taken at the end of a normal expiration and recorded to the nearest 0.1 cm for each subject.

**Construction of percentiles**

The 3rd, 5th, 10th, 25th, 50th, 75th, 85th, 90th, 95th, 97th age- and gender-specific percentiles were constructed for both BMI and WC using the Cole’s LMS method (22, 23). Centile curves were smoothed from raw data using LMSchartmaker Pro Version 2.54 software. The LMS method involves summarizing percentiles at specified ages based on age-specific Box-Cox power transformations. The power transformations enabled normalized growth centile standards to be developed by addressing skewness which was present in the distribution of WC and BMI.
measures (23). The final percentile curves were the result of smoothing three age-specific
curves called L (\textit{lambda}; skewness), M (\textit{Mu}; median), and S (\textit{sigma}; coefficient of variation).
The plotted curves were assessed for goodness of fit using Q-tests for each curve. This was to
ensure that curves were not over-smoothed to lose important information on variability of the
data.

\textbf{Statistical analysis}

All statistical analyses were done using IBM SPSS version 22.0. The WC and BMI scores for
each level of gender were not normally distributed, as assessed by Shapiro-Wilks test \((p<.001)\),
skewness and kurtosis z-scores. Box plots and Q-Q normality plots also suggested positive
skewness of the data, with presence of outliers. Hence, Spearman correlation was used to
examine the relationship between WC and BMI for each gender. The statistical significance was
set at \(p<0.05\).

\textbf{Results}

The mean and SD of the WC and BMI by gender and age are summarized in Table 1. Both WC
and BMI increased with age in both boys and girls. Generally the boys had a higher BMI than
girls. The gender- and age-specific WC values at selected percentiles are presented in Table 2.

Figure 1 shows the smoothed computed WC percentile curves for the 3\textsuperscript{rd}, 5\textsuperscript{th}, 10\textsuperscript{th}, 25\textsuperscript{th}, 50\textsuperscript{th},
75\textsuperscript{th}, 85\textsuperscript{th}, 90\textsuperscript{th}, 95\textsuperscript{th}, 97\textsuperscript{th} percentile for boys and girls. The mean WC increased with age in both
boys and girls although the absolute increase was greater for boys. Interestingly, with increase
in age especially during the post-pubertal years, the WC in boys continued to increase while it
tended to plateau in girls.
Table 1. Mean (SD) for WC and BMI by gender and age of Singaporean children aged 6.00 to 16.99y ($n = 3029$)

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<th></th>
<th>$n$</th>
<th>WC (cm)</th>
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$n$, sample size; SD, standard deviation; WC, waist circumference; BMI, body mass index
Table 2. Gender- and age-specific smoothed waist circumference percentile cutoff values (cm) for Singaporean children aged 6.00 to 16.99y

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Age: completed age in years, e.g. 6 = 6.00–6.99; n denotes sample size
A strong and significant positive correlation was found between WC and BMI in both genders. The Spearman’s correlation coefficient in boys was $r = 0.878$, $p < 0.001$ (two-tailed) and in girls was $r = 0.847$, $p < 0.001$ (two-tailed).

563 children (18.6%) were above the 85th percentile WC cutoff value, 418 children (13.8%) were above the 90th percentile WC cutoff value and 218 children (7.2%) were above the 95th percentile cutoff value.

Figures 2 presents a cross-population comparison of the WC of boys and girls at the 50th percentile and Figure 3 presents the same at the 90th percentile amongst the pediatric populations in Singapore, Hong Kong (24), India (25), Malaysia (15), Turkey (26), Poland (27), Kuwait (28), USA (29), UK (13) and Australia (30). For the sake of standardization, we only included those studies which used LMS method to smooth the WC data and except the USA study, others had measured WC at midway between rib margin and upper border of iliac crest.
Discussion

This report presents the first working WC percentile curves for Singaporean children and adolescents aged 6.0-16.99 years. As the BMI and WC continuously change during growth and maturation, age-specific cutoff values are needed to classify adiposity status among the children and adolescents. This study also presents the mean and distribution of WC at each age and the age-and gender-specific WC cutoff values for Singaporean children and adolescents. The WC
reference cutoffs and percentile curves can serve as a valuable reference tool to screen the pediatric population and identify the children at a higher adiposity-related metabolic risk.

Although WC percentile curves have been developed for various populations, apparently no international or Asian reference cut-offs have been recommended. In our study, the international as well as Asian cross-population comparisons showed distinct differences in WC values and percentile curve patterns between populations thus confirming our second hypothesis and corroborating the need for population-specific cutoff values for use in population-specific screening programmes (8). Our study provides the first basis of defining abdominal adiposity in Singaporean children and adolescents in the school-going age group. Moreover, given the consistently strong associations reported between WC and metabolic risk factor clustering among the children and youth (31, 32), it becomes critical to screen the pediatric population to identify those at a higher risk in order to institute timely preventive and intervention strategies. Developing the population-specific WC cut-offs is a significant step in this direction as it is both a simple and reproducible (31) measure making it feasible for clinical and epidemiological application.

While different cutoff values have been suggested by previous studies, children with WC >90th percentile are more likely to have clustering of multiple risk factors (31), higher insulin resistance and dyslipidemia (33). The results of the study confirmed our first hypothesis showing that 13.8% of the youth had WC >90th percentile which was higher than the prevalence of 12.3% at BMI >90th percentile as well as BMI-based 2011 national school obesity rate of 11% (34). We also found that the boys in the age group of 13.0-13.99y had a lower BMI than girls. This coincides with puberty in boys leading to a disproportionate gain in height compared to weight resulting in false low BMI whereas a higher BMI in girls is related to an earlier onset of puberty (35). Despite so, WC measurements reflected larger waist girth in boys than girls at that age group. This further emphasizes the low sensitivity of BMI as a screening tool (10) and supports
the addition of WC cutoffs to be used in conjunction with the BMI to enhance the sensitivity of
determining pediatric obesity prevalence rates and to identify those at a higher metabolic risk.

Boys had greater WC than girls and this difference seems to be independent of age and obesity
prevalence rates. Similar trends have also been reported in previous studies (36). While such
gender differences in the post-pubertal age group can be explained by the hormonal changes,
similar observations in pre-pubertal children substantiate the role of gender as a significant
determinant of WC even before the onset of adolescence-related major hormonal changes.

The WC percentile curves for girls tended to plateau after the age of 13 whereas it increased
sharply for the boys after this age. Similar trend has also been observed in British (13) and
Iranian children (14). This observation possibly reflects different timings of onset and end of
puberty in boys and girls and the gender-specific influence on WC. The pubertal alterations in
sex and growth hormone levels are associated with changes in the body composition and fat
distribution (37). However, the decline in the WC in girls at age 16y and above may be due to
other reasons like better awareness on obesity and its associated adverse health effects, peer
influences, societal pressures, mass media influences, increased availability and use of
slimming products (38).

Similar to the previous reports (39), a strong positive correlation was found between BMI and
WC for both boys and girls. As WC can vary greatly for a given BMI, this relationship can
provide insights on the advantages of combining age-related WC and BMI to identify children at
a higher metabolic risk as well as avoid misclassifying some children. BMI and WC did not have
strong independent effects when used as continuous variables to predict coronary artery
disease (CAD) risk factors but when BMI and WC were categorized with a clinical approach,
WC provided information on CAD beyond that provided by BMI alone (38). This further supports
combining BMI and WC in practice for prediction of risk factor clustering and identifying children and adolescents at a higher metabolic risk.

This is the first large-scale study reporting the WC percentile curves in Singaporean pediatric population and hence we cannot provide any epidemiological time-trend for this measure. However, the WC curve patterns of Singaporean children and adolescents at 50th and 90th percentile were compared with those reported in other pediatric populations. Results showed that Singaporean children and adolescents had distinct WC percentile curve patterns with Singaporean boys showing a steep rise in WC at both 50th and 90th percentiles especially during the pre-pubertal years. This was even more remarkable while comparing with Asian populations. The girls also showed higher age cutoff values than most countries compared with especially during the pre-pubertal years. Collectively this might suggest that a fraction of Singaporean boys and girls of 9-12 year age group appear to be at increased risk of being overweight.

Differences in the genetic constitutions of different populations can lead to differences in body mass, BMI, body composition and body fat distribution. It has been reported that there is a moderate-to-strong genetic influence in obesity-related phenotypes and children from different populations vary in their rate of proportional growth and fat patterning (40). In addition, various environmental factors like nutritional trends and habits, lifestyle patterns, physical activity and sedentary behaviours, public healthcare and social influences may lead to the differences observed between different populations. These findings further substantiate the existence of ethnic differences in the abdominal adiposity patterns and emphasize the need and significance of developing population-specific WC reference curves for children and adolescents.

While this study has its strengths in terms of being the first to provide reference WC percentile curves and age- and gender-specific cutoffs for Singaporean children and adolescents,
relatively large sample size representative of the school going age group from 6-17 years, providing insights into age and gender-related characteristics and standardized comparison with other populations, it is also purposeful to acknowledge the limitations. The limitations include the cross-sectional study design and hence the inability to determine the association between WC values during childhood with the adulthood metabolic outcomes, lack of information on obesity-related co-morbidities in the sample and effects of pubertal status and maturation status on WC and other anthropometrical indices. Future studies on WC and other anthropometrical indices of Singaporean children and adolescents should address the above limitations. In addition, we also recommend future studies to use the Receiver Operating Characteristic (ROC) analysis to identify optimal, age-adjusted, standardized WC thresholds to increase the specificity and sensitivity for prediction of the elevated risk cluster groups amongst Singaporean children and adolescents of Chinese, Malay and Indian ethnicities.

In conclusion, WC data of children and adolescents from different populations is valuable in order to enhance the feasibility of developing regional or international threshold reference norms and this study provides the first set of WC reference percentile curves for the Singaporean pediatric population. The observed ethnic differences with Asian and other international populations support the premise of developing reference WC percentile curves for the local population. While larger-scale studies are planned in future, these percentiles can be used provisionally in clinical and epidemiological practice for population-specific screening, early detection of children and adolescents who may be at a higher abdominal adiposity-related metabolic risk, international comparisons and to gain more insights on secular trends in growth and pediatric obesity.

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Conflict of interest
We declare no conflict of interest.

References

9. Dekkers JC, Podolsky RH, Treiber FA, Barbeau P, Gutin B, Snieder H. Development of general and central obesity from childhood into adulthood in African American and


