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Study on reference value of waist circumference percentile curve and abdominal obesity cutoff points of children and adolescents aged 6–20 in Macao

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Abstract

Background To develop a standardized percentile curve of waist circumference and abdominal obesity cutoff points for children and adolescents aged 6 to 20 in Macao, the study established a reference for screening abdominal obesity in this population.

Methods The waist circumference data of 10,095 children and adolescents from the 2015–2020 Macao People's Physical Fitness Surveys were used for modeling. The GAMLSS model with four parameters of "median, standard deviation, kurtosis and skewness" was used to construct the standardized percentile curve of waist circumference. Then, the percentile curve-joining adult method was applied to establish the critical value of high waist circumference. Finally, the curves of this study were compared with relevant domestic and international data.

Results (1) Standard curves of waist circumference percentile and standard deviation unit curves were obtained for children and adolescents aged 6–20 years in Macao. (2) Waist circumference of children and adolescents in Macao increased with age. After the age of 12, waist circumference growth gradually decreased. The waist circumference of males was larger than that of females. (3) Analysis of different percentile curves revealed a divergence in growth rates between P50 and P90. Specifically, from ages 6-11 in boys and 6-10 in girls, the annual increase in waist circumference at P90 exceeded that at P50. After these ages, the growth rate at P50 surpassed that at P90.

Conclusion The standardized curves constructed for the percentile waist circumference of Macao's children and adolescents were smooth and tests showed good validity. We recommend using these standardized percentile curves (applicable to ages 6–20 years) and abdominal obesity thresholds (applicable to ages 6–18 years), combined with the other evaluation commonly used indicator of obesity, to identify abdominal obesity in Macao's children and adolescents and therefore, to improve the well-being of Macao's children and adolescents.

Keywords GAMLSS model, Children and adolescents, Waist, Percentile curve, Macao

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Background

In the past 40 years, the global number of obese children and adolescents has increased tenfold [1]. Overweight and obesity rates among children and adolescents in many countries and regions are projected to rise further in the coming years [1]. At the same time, researchers predicted that obesity-related complications-including diabetes, hypertension, and fatty liver would remain prevalent [2, 3]. According to Macao's physical fitness surveillance data, the prevalence of overweight and obesity among children and adolescents in Macao has increased significant since 2005. The prevalence of overweight among children and adolescents in 2005, 2010, and 2015 was 8.8%, 11.3%, and 12.9%, respectively, with statistically significant differences between the years. Similarly, the prevalence of obesity during the same periods was 5.8%, 7.1%, and 9.7%, also demonstrating statistically significant inter-annual differences. [4]. The detection rate of abdominal obesity increased significantly in boys over age 13 and for girls over age 11 [4].While Body Mass Index (BMI) is widely used to classify overweight and obesity, it primarily reflects overall body mass without distinguishing between fat and lean mass. The International Obesity Task Force (IOTF) [5] established internationally recognized age- and sex-specific BMI percentile cutoff points for children, designed to align with adult definitions of overweight (BMI ≥ 25 kg/m^2) and obesity (BMI ≥ 30 kg/m^2) at 18 years of age. However, a critical limitation of BMI is its inability to differentiate between fat mass and non-fat mass, meaning individuals with higher muscle mass may be misclassified as overweight, while those with high central adiposity but lower overall weight may go undetected.

Moreover, central obesity has been shown to be a stronger predictor of obesity-related complications than general obesity. Accumulation of visceral fat, rather than total body fat, is more closely associated with metabolic syndrome, insulin resistance, and cardiovascular diseases such as hypertension and coronary heart disease [6]. Since BMI does not account for fat distribution, it may underestimate the risks associated with central obesity, highlighting the need for alternative measures such as waist circumference (WC), which is increasingly recognized as a more reliable indicator of central adiposity. Some experts have suggested the use of percentile curves of waist circumference and specific percentile thresholds to define central obesity [7]. The reference percentile curve of waist circumference reflecting the change of central obesity with age and sex is the basis for the development of waist circumference threshold value, which is quite necessary in epidemiological studies. Therefore, many countries and regions have established their own standardized percentile curve of waist circumference and high waist circumference thresholds [8–14]. Many cities in China have developed standardized percentile curve of waist circumference for children and adolescents [15–19],however, Macao has not been included. Macao is a special administrative region located in the south of China. LIU Shu et al. found by comparing the 2015 physical fitness test data of 5,235 Macao children and adolescents with those of Chinese mainland, the weight and BMI of children and adolescents in Macao were higher than the average levels in the Chinese mainland [20]. Therefore, it is necessary to establish a reference value of waist circumference that caters to conditions in Macao. Based on the data of Macao's waist circumference measured in 2015 and 2020, and using Generalized Additive Model for Location, Scale, and Shape (GAMLSS) model, we obtained the standardized percentile curve of waist circumference of Macao's children and adolescents aged 6–20 sorting by sex and age, and compared it with other types of the standardized percentile curve of waist circumference at home and abroad. We also identified the critical threshold of high waist circumference on this basis. In terms of the curve, we aim to provide an anthropometric reference for determining abdominal obesity in children and adolescents in Macao, and improve the development of evaluation system for Macao's children and adolescents.

Methods

Research object

This study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the China Institute of Sport Science (approval number: CISS-20190607). The data for this research were collected from the 2015 and 2020 Physical Fitness Surveillance of Macao Special Administrative Region. The participants were children and adolescents aged 6–20 years. In this study, 8 primary and secondary schools and 5 universities were selected from 7 parishes in Macao in 2015, resulting in a total of 13 schools with 4,934 participants. In 2020, 5,161 participants were also selected from the same 13 schools, for a total of 10,095 participants, of which 5,565 were male and 4,530 were female. We sampled the participants by the means of randomized stratified cluster sampling. First, we divided the participants into two categories according to their sex and numerous age groups by 1 year. Then, we randomly selected 2–3 schools in each district of Macao and randomly chose the participants by class in each grade. We selected 55 participants from each sex group and age group among primary and secondary students, and 105 participants among university and college students following the same principle. Schools with special requirements for body size or physical ability for enrollment and application were excluded from our sampling. Meanwhile, all participants had resided in Macao for at least five years. They were in a good physical health, with no congenital, hereditary, acute, or chronic diseases. Also, they were required to have self-care, language expression, and cognitive abilities.

Measuring methods

The participants stood naturally with both shoulders relaxed and arms crossed in front of the chest, without intentionally contracting or raising the abdomen. The testers faced the participants and wrapped the nylon measuring tape around the waist by 0.5–1 cm above the navel, horizontally. The tightness of the tape measure around the waist should be appropriate, ensuring no significant indentation of the skin. The value aligned with the "0" point on the tape measure was the final measured value which was recorded in centimeters, accurate to 0.1 cm. All investigators and researchers were trained to use standardized protocols for data collection with National Physical Fitness Surveillance Type II equipment was used throughout the sampling process; supervisors tracked the whole process, and randomly selected 5% of the population for retesting. All the data were double-entered and compared for verification and error correction.

Research methods

In this study, we used the GAMLSS model to construct waist circumference percentile curves and standard deviation Z-score curves. Nowadays, the primary international methods for establishing growth standards are LMS and GAMLSS. GAMLSS model can handle data with skewed distributions, as well as data exhibiting kurtosis or a combination of both [21]. The percentile curves developed by the model are more representative of the raw data than the LMS method. For example, WHO [22] finally chose the GAMLSS model to build the standardized percentile chart of growth curve for children aged 0–5 years and 5 to 19 years, respectively, based on a comparison of more than 30 growth curve development methods in 2006. Xi B et al. [23] also used the GAMLSS Model to establish international waist circumference percentile curves and cutoff values for children and adolescents with normal weight, using pooled data from eight countries across diverse global regions. These references were specifically designed to screen for central obesity in individuals aged 6 to 18 years. The model was presented in the specific distribution form of D (median μ, standard deviation σ, skewness ν, and kurtosis τ). The key steps of modeling are as follows.

Power transformation coefficients and optimal model selection

First, the optimal submodel in the GAMLSS model system was selected based on the Generalized Akaike Information Criterion (GAIC), which included selecting an optimal fitting sub-distribution model D (BCCGo, BCPEo, and BCTo, etc.), the power transformation index ξ of the independent variable, and the initial degree of freedom for the four parameters of the model fitting curve (dfμ, dfσ, dfν, dfτ). The GAIC criterion includes three indicators: global deviance (GD), Akaike Information Criterion (AIC), and Schwarz Bayes Criterion (SBC), while the Box-Cox power transformation of the independent variable transforms non-normal distribution data into normal distribution. In practical application, when $n < 1{,}000$, the optimal model is generally selected by comparing the minimum AIC of different models; when $n \geq 1{,}000$, the optimal model is selected by comparing the minimum SBC of different models [24].

Fitted parameter curve development

The smoothness of the μ, σ, ν, and τ parameter curves of the model was achieved using B-spline curves and cubic spline functions. First, based on the initial degrees of freedom, the smooth curves of each parameter were obtained. Next, goodness-of-fit diagnostic methods—including Q-statistic tests and the proportion of measured values under theoretical percentile curves—were applied. Fitting residuals from different parameter degrees of freedom were compared to select the optimal model fit [24]. The GAMLSS model provides a variety of goodness-of-fit diagnostics such as Q-statistic tests, the worm plot, and quantitative analysis of residuals. For example, Q-statistic test [25]: when the residual distribution of the fitted curves of the four parameters of the model mean, standard deviation, skewness and kurtosis are not consistent with the standard normal distribution, the difference is statistically significant ($p < 0.05$) when the Q-statistic value shows $|Z| > 1.96$, as well as including the summary Q-statistic, if there is a poor Q-statistic value, it indicates the need to adjust the degrees of freedom of the smoothing parameters with a view to obtaining a better goodness-of-fit effect. This test can be used both to test the goodness-of-fit of the parameters and to explore the parameter curves with better fitting effect by changing the parameter degrees of freedom.

Establishing the parameter fitting curve equation and reference values of the curve

Based on the optimal distribution model and aforementioned degrees of freedom, the parameter equations of the model was established. Finally, the waist circumference percentile reference values and Z-score reference values were derived from the parameter equation.

Verification

Qualitative and quantitative tests of model fit were conducted via Q-statistical tests to verify validity. Additionally, validity was further verified by the proportion of measured values lying below the theoretical percentile curves.

Development of high waist circumference thresholds

This study used the percentile curve extension alignment method to develop a reference value for waist circumference thresholds, i.e., a method that aligns with the Asian adult (18 years old) central obesity standard (85 cm for males and 80 cm for females) to develop central obesity thresholds for children and adolescents in Macao.

Statistical methods

SPSS software was used to perform preliminary processing of the descriptive statistics of the sample data. The GAMLSS modeling process was implemented using R-3.6.2 software, with curve fitting performed via B-spline and cubic spline curves.

Results

Sample eigenvalues

A total of 10,095 participants engaged in the physical fitness test, including 4,934 in 2015 and 5161 in 2020 respectively. Of these, there were 5,565 males and 4,530 females. According to the surveillance data from Macao, the prevalence of overweight among male children and adolescents increased from 14.3% in 2015 to 17.4% in 2020, while the corresponding prevalence among females decreased from 11.2% to 9.8% during the same period. Similarly, the prevalence of obesity in males rose from 11.9% to 13.6%, whereas in females, it showed a slight decline from 7.8% to 7.2%. To increase the validity of the modeling, we eliminated the scattered points that were not part of the overall distribution. The skewness of waist circumference for each age group was positive (Table 1), displaying a right skewness. According to the criteria of [X −3S, X+ 4S], we first deleted the data whose value of height and weight were outside the above interval, and then excluded the data outside the criteria of waist circumference. The final sample included 5,551 males and 4,517 females, for a total of 10,068 participants. The analysis of the eigenvalues of the sample data revealed (Table 1) that the non-normal distribution of kurtosis and skewness for the majority of age groups was significant ($P < 0.05$). Since the traditional method of developing percentile curves had a higher error, it was necessary to develop this criterion after transforming the original data into an approximate normal distribution, which could be achieved by using the GAMLSS method through Box-Cox power conversion.

Table 1 Characteristic values of height, weight and waist circumference of children aged 6–20 in Macao

Age	Boys					Girls				
	N	Height	Weight	Waist	BMI	N	Height	Weight	Waist	BMI
		Average±sd	Average±sd	Average±sd	Average		Average±sd	Average±sd	Average±sd	Average
6	472	119.5±5.7	22.8±4.9	53.9±6.6	16.0	341	118.1±5.4	21.4±3.9	51.9±5.3	15.3
7	476	125.4±6.0	25.7±5.7	56.0±7.5	16.3	357	124.3±5.4	24.7±5.2	54.5±6.8	16.0
8	445	130.9±6.2	29.2±7.1	58.4±8.8	17.0	289	130.2±6.8	28.3±6.4	57.0±7.8	16.7
9	406	136.5±6.3	33.8±8.2	62.6±9.7	18.1	302	136.1±6.8	31.5±7.2	58.9±7.5	17.0
10	369	142.0±6.8	38.3±9.9	65.7±10.9	19.0	290	143.5±7.3	36.8±9.6	61.3±9.1	17.9
11	351	148.3±8.0	43.5±12.8	68.0±12.3	19.8	300	150.9±6.6	43.0±9.7	64.2±8.8	18.9
12	398	156.5±8.3	49.0±12.8	69.7±12.0	20.0	326	154.7±6.3	46.3±9.4	66.0±8.4	19.3
13	381	163.5±7.8	54.8±13.5	71.5±11.8	20.5	279	157.5±5.5	49.9±9.9	67.3±8.7	20.1
14	385	167.7±6.7	58.1±13.4	72.0±11.5	20.7	295	159.2±5.5	51.9±9.6	68.3±8.6	20.5
15	353	170.3±6.0	61.1±13.0	73.4±11.8	21.1	310	160±5.3	53.0±9.1	68.8±7.9	20.7
16	374	172.0±5.9	64.1±14.0	74.8±11.9	21.7	308	160.3±5.6	53.7±9.4	69.4±8.4	20.9
17	398	172.4±6.0	64.3±13.3	74.6±11.2	21.6	362	160.2±5.5	53.2±9.7	69.0±8.5	20.7
18	326	172.0±6.1	63.5±11.5	74.0±9.5	21.5	330	160.1±5.1	53.5±8.5	69.0±7.2	20.9
19	233	173.4±6.2	67.0±12.9	76.9±11.4	22.3	240	160.1±5.7	53.9±9.7	70.0±8.4	21.0
20	198	172.6±6.6	66.9±14.0	76.8±11.0	22.5	201	160.9±5.3	54.3±9.2	70.4±8.2	21.0

GAMLSS model related parameters

Because of the non-normal distribution characteristics of the original sample data, including skewness and kurtosis, the modeling iterations were performed using the sub-distribution models BCCG0(μ, σ, ν, τ), BCT0(μ, σ, ν, τ) and BCPE0(μ, σ, ν, τ) of GAMLSS, respectively. Given that the sample size of this study is greater than n > 1000, the optimal model for both men and women is obtained as the BCPE0 model with Box-Cox power conversion coefficients (ξ) of age of 5.8e-05 and 0.5 for men and women, respectively, based on the generalized minimum deficit pool information criterion (GAIC) with the minimum value of SBC selection. Based on the initial degree of freedom df of the parameters μ,σ,ν,τ, the parameter curves were tuned by iteratively fine-tuning df and according to the Q-statistical test and the principle that the measured values fall into the proportion under the theoretical percentile curve. The final parameter curves with the best fitting effect were obtained for each parameter: mu.df = 6.3, sigma.df = 6.4, nu.df = 5.0, tau.df = 4.3 for the boys' parameters μ, σ, ν, and τ, with a total degree of freedom of 21.1. mu.df = 6.4, sigma.df = 5.9, nu.df = 4.1 for the girls' parameters μ, σ, ν, and τ. nu.df = 4.1, tau.df = 3.6, and the total degree of freedom is 20.0.

Q-statistical tests of the parametric curves revealed that for the quantitative tests (Table 2), except for the residual Z1 of 2.04 for the age group of 7.5–8.5 years for boys and slightly more than Z≦2 for the age group of 17.5 to 18.5 years for girls, the remaining Z values for young children of both sexes were below 2, and the overall *P* values for Z1, Z2, Z3 and Z4 were all greater than 0.05. For the qualitative tests (Table 2), the Q-statistical test plots of the Z-quantile values of the residuals of the model parameters were not statistically significant except for Z1 for the age group 7.5 to 8.5 years for boys and Z2 for the age group 17.5 to 18.5 years for girls, which had squares (squares indicate statistically significant differences in residuals, red indicates negative Z, and blue indicates positive Z). Therefore, both quantitative and qualitative Q-statistical tests indicated good model fit. In addition, the proportion of the measured values falling under the theoretical percentile curve is shown in (Table 3): the range of the difference between the measured values and each theoretical percentile is between 1.2% and 1.4% and 0.1% and 0.2% for males and females, respectively. In summary, the model met the requirements and demonstrated high validity.

Reference values of waist circumference percentile curves and Z-score curves by sex and age

According to the above modeling process, the reference values of P3, P5, P10, P25, P35, P50, P65, P75, P90, P95,

Table 2 Z quantile value Q statistical test table of parameter residuals of fitting model

	Boys					Girls					
Age	N	Z1	Z2	Z3	Z4	Age	N	Z1	Z2	Z3	Z4
5.5~	949	−0.51	−0.38	0.70	−1.00	5.5~	698	−0.11	−0.18	0.47	−0.29
7.5~	445	−2.04	0.40	0.93	0.46	7.5~	289	−0.03	0.83	0.85	−1.95
8.5~	406	0.37	−0.44	−0.72	0.45	8.5~	591	−1.05	−0.16	0.04	−0.24
9.5~	718	0.10	0.34	0.65	−1.38	9.5~	300	0.68	0.13	−0.87	0.54
11.5~	398	−0.76	1.41	−1.01	0.97	11.5~	605	0.20	−0.03	0.19	−0.39
12.5~	765	−0.86	−1.05	0.91	−0.08	12.5~	294	−0.25	−0.34	0.26	−1.00
14.5~	352	−1.43	−0.18	0.27	1.00	14.5~	618	0.14	−0.35	−0.77	−0.19
15.5~	772	−0.90	−0.05	1.05	0.21	15.5~	362	0.25	1.19	0.75	−0.93
17.5~	326	−0.45	−0.82	1.18	−0.50	17.5~	330	−1.11	−2.09	1.20	−0.72
18.5~	420	−0.60	0.49	−0.57	−0.33	18.5~	430	0.01	0.81	−0.34	−0.09
TOTAL	5551	9.28	4.64	7.03	5.65	TOTAL	4517	2.98	7.46	4.50	6.82
P-tot	/	0.06	0.43	0.43	0.43	P-tot	/	0.50	0.33	0.60	0.28

N denotes the number of people in that age group , Z1, Z2, Z3 and Z4 denote the residuals of the fitted curves for parameters μ, σ, ν and τ, respectively, and the larger the Z value, the smoother the curve but the poorer the fit. The criterion for passing the fitted curves for each parameter is that the residuals |Z| < 1.96 (*P* > 0.05)

Table 3 Percentage of sample size under the theoretical percentile curve of GAMLSS model

Theoretical Percentile curve		0.4	2	10	25	50	75	90	98	99.6
Percentage of sample	Boys	0.4	2.0	9.9	25.2	50.0	75.0	90.0	98.0	99.6
size	Girls	0.5	2.1	9.4	24.6	51.4	75.8	88.8	97.9	100.0

P97 and 2SD, SD, 0SD, 1SD, 2SD for waist circumference by sex and age were derived (Tables 4 and 5), and the corresponding waist circumference percentile curves are shown (Figs. 1 and 2).

The age growth of waist circumference for both boys and girls showed a significant growth trend, but there were large differences in the growth at each age. Specifically, for boys, the percentile curves showed a rapid increase in waist circumference between the ages of 6 and 11 years, such that the absolute annual growth intervals for P50 and P90 were 2.3–2.9 cm and 3.3–5.4 cm, and the annual growth intervals for P50 and P90 were 3.6%−5.4% and 4.1%−7.9%. The increase gradually decreased with age during the ages of 11 and 13 years, the increases of P50 and P90 decreased with age from 13 to 20 years old and grew more slowly. For girls, the percentile curves show a rapid increase in waist circumference between the ages of 6 and 11 year, with annually

Table 4 Reference of percentile and Z score for 6–20 years Boys in Macao (cm)

Age	Percentile reference											Z score reference					
	P3	P5	P10	P25	P35	P50	P65	P75	P90	P95	P97	−2S	−1S	0S	+1S		+2S
6	46.0	46.6	47.6	49.6	50.7	52.4	54.4	56.1	60.7	64.4	67.4		45.7	48.4	52.4	58.4	69.2
7	47.0	47.6	48.6	51.0	52.4	54.7	57.5	59.9	65.5	69.5	72.5		46.7	49.6	54.7	62.7	74.2
8	48.1	48.8	49.9	52.7	54.4	57.5	61.6	64.1	70.7	75.0	78.0		47.8	51.1	57.5	67.6	79.6
9	49.6	50.3	51.7	54.8	56.9	60.6	65.0	68.5	76.1	80.6	83.6		49.3	52.9	60.6	72.6	85.1
10	51.2	51.9	53.4	56.9	59.3	63.5	68.4	72.4	80.7	85.5	88.5		50.8	54.8	63.5	76.9	90.1
11	52.6	53.5	55.0	58.8	61.3	65.8	71.1	75.3	84.0	88.9	92.0		52.3	56.5	65.8	80.0	93.6
12	54.2	55.1	56.7	60.5	63.1	67.6	73.0	77.2	86.0	90.9	94.1		53.8	58.2	67.6	82.0	95.7
13	55.9	56.8	58.4	62.2	64.8	69.1	74.4	78.5	87.2	92.2	95.4		55.5	59.9	69.1	83.2	97.0
14	57.5	58.4	60.0	63.7	66.2	70.4	75.5	79.6	88.1	93.1	96.4		57.1	61.5	70.4	84.1	98.0
15	59.0	59.8	61.4	65.1	67.5	71.6	76.5	80.4	88.8	93.9	97.3		58.6	62.9	71.6	84.9	99.1
16	60.3	61.1	62.7	66.3	68.7	72.6	77.3	81.2	89.5	94.6	98.1		59.9	64.2	72.6	85.6	99.9
17	61.4	62.3	63.8	67.4	69.6	73.5	78.0	81.7	89.9	95.1	98.7		61.0	65.3	73.5	86.1	100.5
18	62.2	63.1	64.7	68.2	70.4	74.1	78.6	82.1	90.2	95.4	99.0		61.8	66.2	74.1	86.4	100.9
19	62.9	63.8	65.4	68.9	71.1	74.7	79.0	82.4	90.4	95.6	99.2		62.5	66.8	74.7	86.6	101.2
20	63.4	64.4	66.0	69.5	71.6	75.1	79.3	82.7	90.5	95.7	99.4		63.0	67.4	75.1	86.7	101.4

Table 5 Reference of percentile and Z score for 6–20 years Girls in Macao (cm)

Age	Percentile reference											Z score reference				
	P3	P5	P10	P25	P35	P50	P65	P75	P90	P95	P97	−2S	−1S	0S	+1S	+2S
6	44.9	45.5	46.5	48.4	49.5	51.0	52.8	54.3	58.3	61.4	63.8	44.6	47.4	51.0	56.3	65.2
7	45.8	46.5	47.7	49.9	51.2	53.2	55.5	57.5	62.5	66.3	69.3	45.5	48.7	53.2	60.0	71.0
8	46.8	47.6	48.9	51.6	53.1	55.5	58.2	60.6	66.4	70.7	73.9	46.5	50.1	55.5	63.5	75.7
9	48.2	49.0	50.5	53.4	55.1	57.8	60.9	63.5	69.7	74.1	77.3	47.8	51.8	57.8	66.6	79.1
10	49.9	50.8	52.3	55.5	57.3	60.2	63.5	66.2	72.7	77.1	80.3	49.4	53.7	60.2	69.5	82.0
11	51.8	52.8	54.4	57.7	59.6	62.6	66.0	68.7	75.1	79.5	82.5	51.3	55.8	62.6	72.1	84.2
12	53.7	54.7	56.3	59.7	61.6	64.6	68.0	70.7	76.9	81.1	84.0	53.2	57.8	64.6	73.9	85.6
13	55.2	56.2	57.9	61.2	63.1	66.1	69.4	72.0	78.1	82.2	85.0	54.7	59.3	66.1	75.2	86.5
14	56.4	57.4	59.1	62.4	64.3	67.1	70.4	73.0	78.9	82.9	85.6	55.9	60.5	67.1	76.1	87.1
15	57.3	58.3	59.9	63.2	65.1	67.9	71.1	73.6	79.5	83.4	86.2	56.8	61.4	67.9	76.7	87.6
16	57.8	58.8	60.5	63.7	65.5	68.3	71.5	74.0	79.9	83.9	86.7	57.4	61.9	68.3	77.1	88.2
17	58.2	59.2	60.8	64.0	65.8	68.5	71.7	74.2	80.1	84.1	86.9	57.7	62.2	68.5	77.2	88.5
18	58.5	59.4	61.0	64.1	65.9	68.6	71.7	74.2	80.0	84.0	86.9	58.0	62.4	68.6	77.2	88.4
19	58.7	59.7	61.2	64.3	66.1	68.7	71.7	74.2	80.0	84.0	86.9	58.3	62.6	68.7	77.2	88.5
20	59.1	60.0	61.5	64.5	66.3	68.9	71.8	74.3	80.1	84.1	87.0	58.6	62.8	68.9	77.3	88.5

Px denotes the percentile and X denotes the Xth percentile

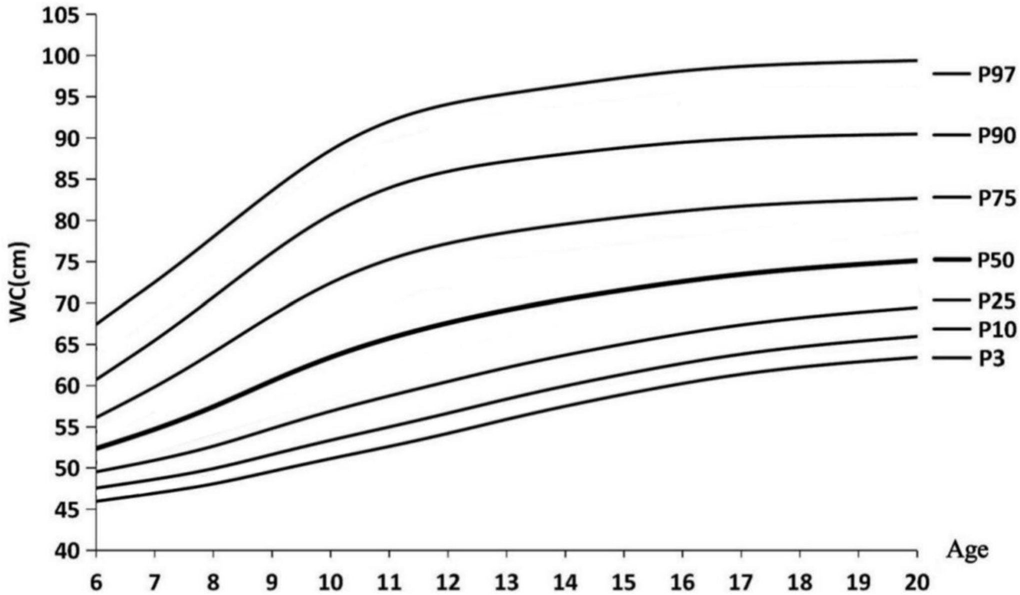

Fig. 1 Waist circumference percentile reference chart for male children and adolescents aged 6~20 years in Macao

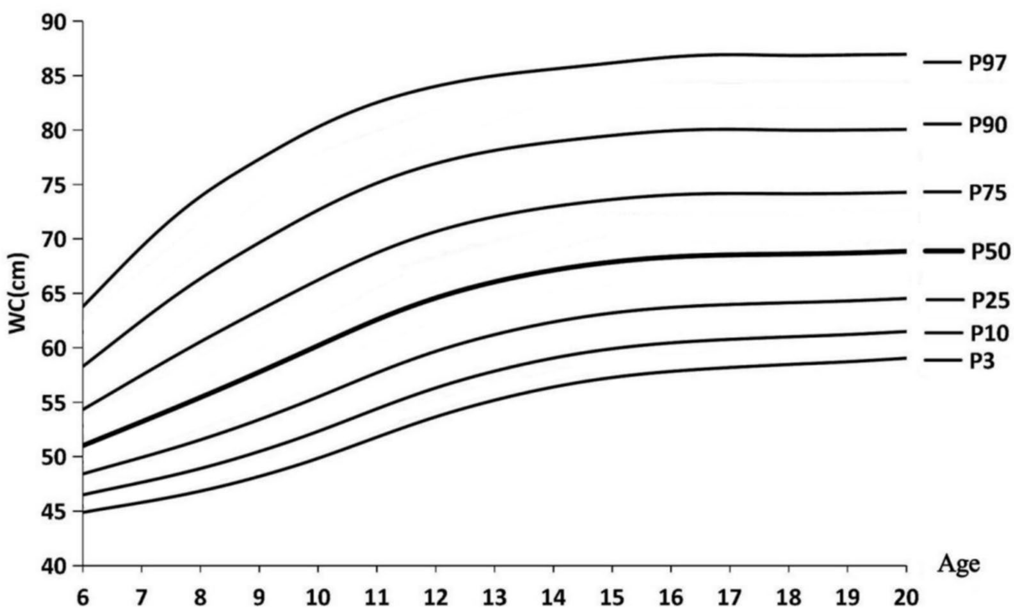

Fig. 2 Waist circumference percentile reference chart for female children and adolescents aged 6~20 years in Macao

net growth ranges of 2.2–2.4 cm and 2.4–4.2 cm for P50 and P90, and annual growth ranges of 4.0%–4.3% and 3.3%–7.2% for P50 and P90. The increase gradually diminishes with age between the ages of 11 and 15 year, with annually net growth ranges of 0.8–2 cm and 0.6–0.8 cm for P50 and P90, and 1.2%–3.2% and 0.8%–2.4% for P50 and P90. P50 and P90 growth rates decreased yearly between the ages of 15 and 16 years, and the percentile remained basically the same from 16 to 20 years old.

From the sex perspective, the percentile curve reference values of waist circumference were larger in boys than in girls in each age group, especially in the higher percentile, such as the mean differences of 1.8 cm, 3.6 cm and 8.0 cm between men and women at P10, P50 and P90 ages, respectively. In addition, the sex differences of the same percentile curve reference values gradually increased with age.

The analysis of percentile curves indicated distinct patterns in waist circumference growth rates between P50 and P90 across age groups. For boys aged 6–11 years, the annual increase in P50 was lower than that of P90, whereas after age 11, the growth rate of P50 surpassed P90. Similarly, for girls aged 6–10 years, the annual increase in P50 was lower than P90, with this trend reversing after age 10.

Thresholds of High waist circumference for children and adolescents in Macao

The standardized percentile curve of waist circumferences established in this study are arbitrary percentile curves, and there is the one-to-one correspondence between waist circumference values and percentile curves. From the above established percentile standard curve for Macao's children and adolescents, it can be seen that the waist circumference of 85 cm for 18-year-old male in Macao is between the 75 th and 90 th percentile, while the waist circumference of 80 cm for 18-year-old female is in the same curve as the 90 th percentile. For male children and adolescents, through the inverse of the parametric equation of the percentile curve, we can get the percentile corresponding to the waist circumference of 85 cm at the age of 18 for male children is P81.4, so we can get the critical values of high waist circumference (central obesity) for children and adolescents aged 6 ~ 18 in Macao (Table 6).

Discussion

Comparison of waist circumference on domestic and international levels

This study suggested that waist circumference of children and adolescents in Macao increased with age. It displayed a rapid growth for both boys and girls of 6–11 years old, and the growth gradually slowed down thereafter. To further investigate the waist circumference characteristics of children and adolescents in Macao, comparative analyses between Macao, the Chinese mainland and other countries were conducted as follows:

On a domestic level, in comparison with the waist circumference of Shanghai [18], Beijing [17], Hong Kong [15] and the waist circumference of the national [16] level in China, we found that the waist circumference in Macao exhibited distinct characteristics (Figs. 3 and 4). First, the 50 th percentile waist circumference values were higher among males in Macao than in Beijing and Hong Kong. Values also exceeded the national average

Table 6 Threshold values of high waist circumference (central obesity) for children and adolescents aged 6 ~ 18 years in Macao

Age	6	7	8	9	10	11	12	13	14	15	16	17	18
Boys	58.6	62.8	67.0	71.3	75.5	78.5	80.5	81.7	82.7	83.5	84.1	84.6	85.0
Girls	58.3	62.5	66.4	69.7	72.7	75.1	76.9	78.1	78.9	79.5	79.9	80.1	80.1

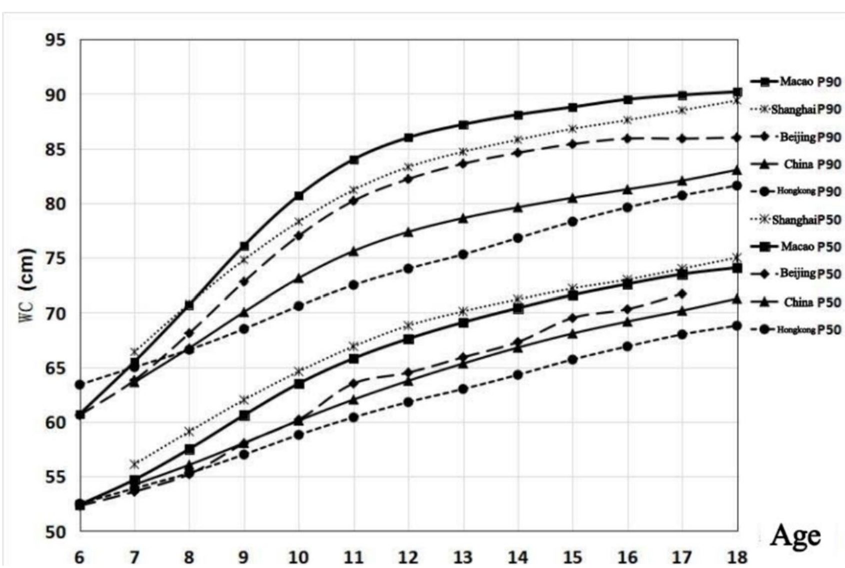

Fig. 3 Comparison of waist circumference P50 and P90 of male children and adolescents in Macao with other Chinese cities

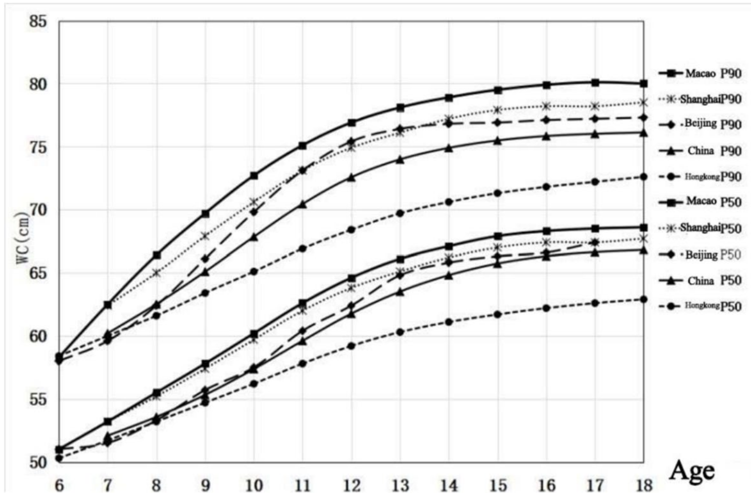

Fig. 4 Comparison of waist circumference P50 and P90 of female children and adolescents in Macao with other Chinese cities

but were slightly lower than in Shanghai. The 50 th and 90 th percentile waist circumference values for female children and adolescents were higher than in Shanghai, Beijing, Hong Kong and China. The growth in Macao before the age of 12 years was greater than that of other cities and the whole country. In summary, the waist circumference of children and adolescents was at a relatively higher level.

On an international level, compared with other countries, it was found that the waist circumference P50 of both male and female children and adolescents in Macao was lower than that of western countries such as the United States [12], India [11] and Latin America [9] (Figs. 5 and 6). However, the values were close to that of Singapore [10], probably because of the large numbers of Chinese in Singapore. The measurement techniques for waist circumference in the above countries are basically the same, and the data were collected in the last 10 years. The measurement methods and sample time do not indicate the great differences, therefore, the main factors affecting waist circumference are more likely to be inter-ethnic differences, followed by human society and natural environment, etc.

Advantages of linking to adult standards for develop waist circumference thresholds in children and adolescents

Currently, the more recognized threshold value standard for central obesity in Asian adults is the Asian Obesity Collaborative Organization recommendation of 85 cm waist circumference for men and 80 cm for women [6].

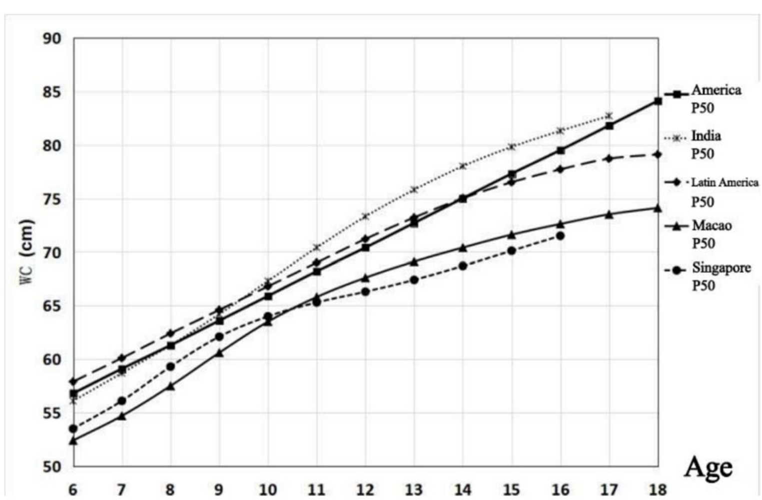

Fig. 5 Comparison of waist circumference P50 of male children and adolescents in Macao with foreign countries

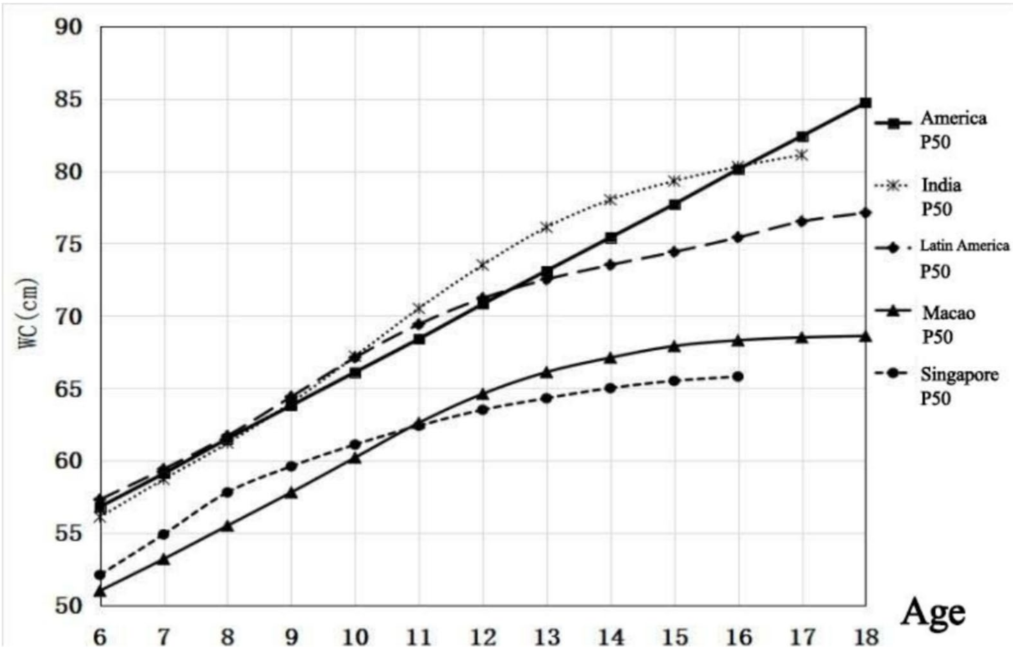

Fig. 6 Comparison of waist circumference P50 of female children and adolescents in Macao with foreign countries

For children and adolescents, central obesity thresholds are primarily developed via three methods: the percentile method, receiver operating characteristic (ROC) curve method [26], and linking to adult standards (age 18).

First, the percentile method usually uses P90 as the threshold for central obesity, as recommended by the International Diabetes Federation as the threshold for diagnosing central obesity, which requires a large sample size and changes accordingly with time, so the study also noted that necessary revisions will be made if further evidence is available [27]. Second, the ROC method is used to developing a threshold value for abdominal obesity based on data on obesity-related chronic diseases such as diabetes, hypertension, and fatty liver, and the method is the gold standard for developing a threshold value for waist circumference in adults. However, unlike adults, children and adolescents show obesity and chronic diseases for a shorter period of time and clinical symptoms are not obvious, so the effect of using metabolic indication data to infer the waist threshold of this population is worse than that of adults [26]. Third, the linking method aligns percentile curves of children and adolescents with adult critical values (age 18) to derive age-specific waist circumference thresholds. The method has been widely used in the international development of percentile curve thresholds for children and adolescents, for example IOTF used the extended percentile curve convergence method to develop overweight and obesity thresholds for children and adolescents aged 2 to 18 years [5], and the Chinese Obesity Task Force also used it to develop overweight and obesity thresholds for children and adolescents aged 7 to 18 years in Chinese mainland [28]. Therefore, this study used the extension alignment method of percentile curve to develop a reference for waist circumference thresholds, i.e., a method that aligns with the Asian adult (18 years old) central obesity standard (85 cm for males and 80 cm for females) to develop central obesity thresholds for children and adolescents in Macao.

Advantages and limitations

This study utilized the waist circumference data of 10,095 children and adolescents in Macao in 2015 and 2020 to construct the percentile curve of waist circumference in Macao through the GAMLSS model, and then used the standardized percentile curve to connect to the adult method to develop the threshold value of high waist circumference to provide a method for identifying central obesity in children and adolescents in Macao. This study has the advantage of a large sample size and provides the first standardized waist circumference percentile curves and high waist circumference thresholds for children and adolescents in Macao.. However, these thresholds were developed using the percentile curve alignment method with a large sample, whereas the most objective criteria for obesity should be based on health outcomes.. This study has several limitations. First, our sample was limited to students in schools and did not include students who did not attend school. Therefore, the sampling of that population should be considered in future. Second, our data were from two cross-sectional surveys (2015 and 2020), whereas the best source of data would have been obtained through a longitudinal study of growing children and adolescents. Last, the prevalence of obesity among children and adolescents in Macao exceeded that in other Chinese regions. While the waist circumference percentile curves and thresholds developed in this study provide localized reference values for Macao's children and adolescents, we acknowledge that the high prevalence of obesity in this population may lead to potential underestimation of abdominal obesity risk if solely relying on these thresholds. To address this limitation, we recommend combining waist circumference with additional anthropometric indicators (e.g., BMI, waist-to-height ratio) and clinical metabolic parameters (e.g., blood pressure, lipid profiles) for comprehensive obesity screening.. Furthermore, future studies should validate the health relevance of these thresholds by linking them to data on obesity-related comorbidities (e.g., hypertension, insulin resistance) in Macao's youth. This would allow refinement of the cutoffs based on actual disease risk rather than purely statistical distributions.

Conclusions

In this study, a GAMLSS model incorporating four parameters of median, standard deviation, kurtosis, and skewness was used to construct a standardized percentile curve of waist circumference for Macao's children and adolescents based on the Macao National Physical Fitness Surveillance data in 2015 and 2020.This study provides the first population-specific reference values for waist circumference in Macao's children and adolescents, The constructed curve were smooth and stable, with model fit confirmed by goodness-of-fit tests. The standardized percentile curves showed that waist circumference increased with age, with rapid growth between 6–11 years and a gradual decline after age 12. Males consistently had larger waist circumferences than females. Basically, it was consistent with the waist circumference characteristics of major cities in Chinese mainland, but children and adolescents waist circumference in Macao was at a higher level compared to the domestic. Based on the standardized percentile curves established in this study, the threshold values of waist circumference were developed using the splicing method. The standardized waist circumference percentile curves developed in this study apply to children and adolescents aged 6–20 years, providing a comprehensive reference for population distribution. In contrast, the central obesity thresholds (85 cm for males and 80 cm for females) were derived by aligning the 18-year-old adult standards with the percentile curves through backward extrapolation, thus applicable to individuals aged 6–18 years for screening purposes, and it was suggested that waist circumference combined with other anthropometric indicators and clinical metabolic parameters should be used for comprehensive identification of obesity in children and adolescents in Macao, so as to more comprehensively assess obesity-related diseases and thus improve the health of children and adolescents in Macao.

Abbreviations

BMI	Body Mass Index
GAMLSS	Generalized Additive Model for Location, Scale, and Shape
GAIC	Generalized Akaike Information Criterion
GD	Global deviance
AIC	Akaike Information Criterion
SBC	Schwartz Bayes Criterion
ROC	Receiver operating characteristic curve
IOTF	International Obesity Task Force

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Authors' contributions
LP J: Writing - Original Draft and Conceptualization. AY Z: Formal analysis and Validation. CJ T: Review and guide. YB G: Writing - Review & Editing. JH: Visualization and Data Curation. XP: Writing - Review & Editing and Visualization. XH Z: Project administration. YF Z: Supervision.

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Data availability
The datasets generated and analysed during the current study are not publicly available but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the China Institute of Sport Science (approval number: CISS-20190607). Written informed consent was obtained from individual or guardian participants.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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