GROWTH STANDARD CHARTS OF HEIGHT, WEIGHT AND CHEST CIRCUMFERENCE OF PRE-SCHOOL CHILDREN 3-6 YEARS OF AGE IN CHINA BASED ON LMS METHOD

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Abstract. In this study, percentile growth charts of height, weight and chest circumference of pre-school children 3-6 years of age in China were constructed to provide references for evaluating growth and development of pre-school children. Percentile growth criteria of height, weight and chest circumference and their curves were formulated using Lambda Mu Sigma method in accordance with the physical fitness data of 50,702 children in 31 provinces of mainland China in 2014, from which standardized reference charts of L, M and S parameters as well as percentiles of the ages were produced. Chi-square test of goodness of fit showed no statistically significant difference between frequency distribution of fitted and actual values. Based on the 50th percentile of the 4 years of interest, increase in rates was weight > height > chest circumference. Comparison between China and WHO standards for 50th percentile showed height and weight of male children according to China standard were higher than that of WHO; however height and weight of female children was the same and higher when comparing China to WHO standard respectively, but weight of female children in the first 60 months was higher and thereafter became lower when comparing China standard to WHO standard. This is the first time standardized height-, weight- and chest circumference-for age growth charts of children from 3 to 6 years old nationwide in mainland China were constructed providing references for use to evaluate growth and development of pre-school children in the country and this type of study should be popularized in the field of preventive health care.

Keywords: chest circumference, weight, height, Lambda Mu Sigma method, percentile growth chart, pre-school children, China

INTRODUCTION

Physical fitness of pre-school children has important effects on the physical health of adolescents, adults, and elderly people. Body shape index can reflect growth, nutrition and health status of

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children (Win-MM-Khin *et al*, 2011), and height, weight, and chest circumference are important indicators of body shape. China attaches great importance to physical fitness surveys of children all the time. For example, during 1975 - 2015 the Ministry of Public Health of China monitored the body shape indexes of children <1-6 years of age in nine cities every 10 years (Capital Institute of Pediatrics, 2018). In the 2005 survey, Lambda Mu Sigma (LMS) was adopted to establish percentile curves of height-for-age and weight-for-age in nine cities (Hui *et al*, 2009). The National Physical Fitness Monitoring Center conducted four surveys, in 2000, 2004, 2010, and 2014, of children 3-6 years of age in 31 provinces, mainly providing descriptive statistics of the monitored data and established standard percentile reference curve without considering the skewness of data distribution (General Administration of Sport of China, 2017). More recently, a number of institutions and researchers have used the LMS method to establish percentile reference standard for body shape indicators in individual cities (Jiang *et al*, 2007). However, there is no reference standard for percentile of height, weight and chest circumference for the whole of China.

In order to evaluate children's growth and development, many international organizations and countries have developed physical percentile reference standards and growth curves involving pre-school children 3-6 years of age, such as the height, weight and body mass index (BMI) percentile standards formulated by WHO (2000),and CDC (Wei *et al*, 2000). However, the children's growth and development standards of WHO and CDC do not include data from China.

Hence, this study will applied LMS method to establish a set of percentile growth standard charts of the height-for-age, weight-for-age and chest circumference-for-age for children of 3-6 years of age to explore their height, weight and chest circumference characteristics, and to provide reference for the Education Management Department, kindergartens, parents, and other related personnel. This study should provide a more accurate, simple and practical growth evaluation tool for medical, healthcare and scientific research.

MATERIALS AND METHODS

Study population

In 2014, the Chinese National Physical Fitness Surveillance Center monitored the physical fitness of 3-6 years old children nationwide (General Administration of Sport of China, 2017). This study employed the principle of stratified sampling in all 31 provinces (autonomous regions and municipalities directly under the central government) in mainland China. The procedures were as follows: (i) three prefecture-level cities under the jurisdiction of the provinces were randomly selected in each province; (ii) test kindergartens in the prefecture-level cities were randomly selected and grouped according to gender and age, with 1,600 children sampled from each province; (iii) validated data of 50,702 children (25,381 males and 25,321 females) were collected nationwide.

The study protocol was approved by General Administration of Sport of China and other participating institutes [No. quntizi (2014-5)]. Prior written informed consent was obtained from legal guardian of each participant.

Data collection

The study period was from April to August, 2014 and test equipment was designed and distributed by the National Physical Fitness Surveillance Center. The

test method was implemented according to China National Physical Fitness test program (General Administration of Sport of China, 2017).

Optimization of sample data before modeling

Before construction of the model, in order to eliminate influence of aberrant data on the model, data that were too high or too low were deleted as has previously been conducted by Cole *et al* (2000), who exclude values outside the range M-3S and M+4S. Measurements of 75 (0.30%) male and 64 (0.25%) female participants were excluded, resulting in 25,306 male and 25,257 female children in the study.

Research methodology

Modeling using age group approach. Children 3-5 years (37-72 months) old, 6 months old and 6 years old were assigned into different groups, making a total of 7 groups (Table 1). In the study, the unit of age is month.

Modeling using LMS method. LMS method provides a way of obtaining normalized growth percentile standards (Cole, 1990; Cole and Green, 1992).The model is constructed by transforming data of each group of different ages with skewed distribution into an approximate normal distribution of non-biasedness using three parameters, namely, L, M and S where L is a BOX-COX power conversion value, M a median value and S is coefficient of variation. Specific steps are as follows: (i) L, M and S parameters are calculated for each age group; (ii) L(t), M(t) and S(t) fitting curves and functional equations are established using a cubic spline interpolation method; (iii) parametric equations of L(t), M(t), and S(t) are converted into percentile curve equation: $C100\alpha(t) = M(t)(1 + L(t)S(t)Z\alpha) / L(t)$ to obtain any percentile for each age, where $C100\alpha(t)$ is the value at the $l00\alpha$ percentile curve at age t, $Z\alpha$ is the normal dispersion when the tail area is $1\text{-}\alpha$ (*eg*, if $\alpha = 0.97$ corresponds to the 97th percentile, then $Z = 1.88$), and L(t), M(t) and S(t) are values of each curve corresponding to age t; and (iv) the corresponding percentile charts of height-for-age, weight-for-age, and chest circumference-for-age for male and female children 3-6 years old are drawn.

Testing LMS model. Two procedures were performed to test the robustness of the LMS model. In the first procedure, difference between the fitting values of 15th, 50th and 85th percentile, respectively and the actual value was compared to determine the fitting degree of the constructed percentile curve to the actual curve. In the second procedure, goodness of fitted values was calculated to test the consistency of the actual distribution and the distribution of fitted percentiles using a chi-square method as follows: (1) raw data were converted to *Z* scores using the LMS inverse equation:

$$Z = \frac{\left(\frac{\text{Measurements}}{M}\right)^{L} - 1}{LS}$$

(2) proportions of individual *Z* scores of each age group in the 3rd, 5th, 15th, 50th, 75th, 85th, 95th, and 97th intervals of the percentile curve were calculated. A chi-square test was conducted to examine whether the actual and the expected ratios were within each percentile interval.

RESULTS

Basic analysis of sample data

Height, weight and chest circumference of pre-school children 3-6 years of age collected in China, 2014 showed body weight > chest circumference > height, with skewness positive coefficients (deviations to the right) for body weight

Table 1
Descriptive statistics of height, weight and chest circumference of Chinese preschool children aged 3-6 years.

Sex	Age		*n*	Height			Weight			Chest circumference		
	year	Mouth		$\bar{x}$	SD	Skew -ness	$\bar{x}$	SD	Skew -ness	$\bar{x}$	SD	Skew -ness
Boys	3.0	37–42	1912	100.2	5.7	0.03	16.0	2.3	1.14	52.4	3.1	0.50
	3.5	43–48	4377	103.0	5.0	-0.02	16.8	2.4	1.14	53.2	3.0	0.81
	4.0	49–54	3179	106.0	4.9	0.21	17.8	2.5	1.34	53.9	3.2	0.81
	4.5	55–60	3242	109.5	5.0	0.16	18.9	3.0	1.55	55.0	3.5	1.18
	5.0	61–65	3506	112.7	5.1	0.04	20.1	3.3	1.32	55.9	3.8	1.08
	5.5	66–72	2980	115.6	5.2	-0.15	21.2	3.6	1.20	56.8	3.9	0.95
	6.0	73–84	6185	119.7	5.5	-0.15	23.0	4.3	1.27	58.2	4.5	1.02
Girls	3.0	37–42	2057	99.0	5.4	0.41	15.3	2.1	0.85	51.3	3.0	0.20
	3.5	43–48	4192	101.7	4.8	0.12	16.1	2.1	0.87	52.1	2.9	0.46
	4.0	49–54	3299	104.8	4.9	0.33	17.0	2.5	1.27	52.6	3.1	0.65
	4.5	55–60	3175	108.3	4.9	-0.07	18.1	2.7	1.03	53.6	3.3	0.84
	5.0	61–65	3603	111.2	4.9	-0.06	19.0	2.9	1.26	54.2	3.5	1.01
	5.5	66–72	2818	114.6	5.3	-0.27	20.3	3.6	1.08	55.2	3.8	0.97
	6.0	73–84	6177	118.1	5.5	-0.21	21.6	3.6	1.08	56.2	3.9	0.87

and chest circumference, but in certain age groups negative coefficients were observed for skewness in height (Table 1).

Comparison between fitted values and measured values, and test of goodness of model fitting

Comparative results of the percentage difference between fitted and actual values in this study demonstrated; (i) for height, 50th percentile of male and female children is between -0.2% and 0.5% and between - 0.6% and 0.4%, respectively; (ii) for weight, 50th percentile of male and female children is between -0.7% and 0.6% and between -0.6% and 0.3%, respectively; and (iii) for chest circumference, 50th percentile of male and female children is between -0.6% and 0.5% and between -0.4% and 0.6%, respectively (Table 2). Percent difference between fitted and actual value at the 50th percentile was within 1.0%, indicating the percentile standard developed by this study closely matches the original measured value distribution. In addition, the percentile curve was smooth and the trend towards the percentile curve was consistent (Fig 1).

Comparisons of the fitted values of height, weight and chest circumference with frequency distribution of the measured values are not statistically significant (chi-square test), (Table 3). No statistically significant difference was observed between the fitted curve and the actual curve, and the goodness-of-fit of the percentile curve is comparatively high.

Height-, weight- and chest circumference-for-age growth standard charts

Using the conversion formula: Y = 12X + 3.5, where X is the "half-year" of 3-5 years old children, and Y is "month", monthly L, M, and S parameters, percentile growth standard charts were generated (Fig 1). (Data used to produce Fig 1 will be provided upon request to CJ.) Using the 50th percentile as a reference, the following were observed of children 3-6 years of age: (i) height of male children increased 24.3 cm in the four years and that of 3-year olds (36-48 months), 4-year olds (48-60 months), 5-year olds (60- 72 months), and 6-year olds (72-84 months) increased by 6.2, 6.1, 6.0, and 6.0 cm, respectively. Height of female children increased 24.1 cm in the four years, with 3-, 4-, 5-, and 6-year olds increasing a steady 6.0, 6.1, 6.0, and 6.0 cm, respectively; (ii) male children gained 8.2 kg in weight over the 4 years, with 3-, 4-, 5-, and 6-year old having increased 1.8, 1.9, 2.1, and 2.4 kg in weight, respectively, a steady increase with age. Female children gained 7.3 kg over the 4 years, with 3-, 4-, 5-, and 6-year olds having increased 1.6, 1.9, 2.0, and 1.8 kg in weight, respectively, the 5-year olds gaining the most weight; (iii) chest circumference of male children increased 6.8 cm in the 4 years, with 3-, 4-, 5-, and 6-year olds having increased 1.6, 1.6, 1.8, and 1.8 cm, respectively. Female children chest circumference increased 5.6 cm in 4 years, with 3-, 4-, 5-, and 6-year olds having increased 1.3, 1.3, 1.4, and 1.6 cm, respectively. Both male and female children grow faster in the later than the early 2 years. Weight-for-height increased with age in male children whereas in female children this parameter decreased with age.

The percentile curves of height for male and female children were slightly narrower at 4 and 5 years of age and wider at 3 and 6 years of age (Fig 1A).The percentile curves of weight gradually widened with increase in age, with changes in high percentiles being greatly larger than 50th percentile, whereas changes in low percentile, such as 3rd and 5th percentiles, were slight with each age, indicating an increase in the overweight proportions of 5- and 6-year old children (Fig 1B). The percentile curves of chest circumference had characteristics similar to those of weight (Fig 1C).

The overall height and weight of pre-school children (Fig 2) were greater than the WHO (2006) standards. China standard at the 50th percentile for height of male pre-school children was higher than that of WHO, and the percentile curve spacing between that of China and WHO decreased with increase in age, differences of 0.62-2.16 cm (average of 0.99 cm). China standard at the 50th percentile for height of female pre-school children was greater than that of WHO during 37-54 months of age and became similar to that of WHO during 55-84 months of age. In a similar manner, China standard at the 50th percentile for weight of male pre-school children was greater than that of WHO, and the percentile spacing between the two standards gradually decreased with age, with differences at 37-84 months of age between 0.46 and 83 kg (average difference of 0.58 kg). China standard at the 50th percentile for weight of female pre-school children was higher than that of WHO during 37-59 months of age, overlapped at 60 months of age and was smaller during 61-84 months of age.

DISCUSSION

Our survey data were derived from the National Physical Fitness Survey, 2014

Table 2
Comparisons of fitted with measured data of height, weight and chest circumference of pre-school children 3-6 years of age in China, 2014.

Parameter	Years of age	Male									Female								
		15th percentile			50th percentile			85th percentile			15th percentile			50th percentile			85th percentile		
		Fitted data	Measured data	Δ*	Fitted data	Measured data	Δ*	Fitted data	Measured data	Δ*	Fitted data	Measured data	Δ*	Fitted data	Measured data	Δ*	Fitted data	Measured data	Δ*
Height (cm)	3.0	94.9	94.6	0.4	100.2	100.1	0.1	105.4	106.0	-0.6	94.0	93.6	0.5	98.8	98.5	0.4	104.0	104.5	-0.4
	3.5	98.2	98.1	0.1	103.2	103.0	0.2	108.5	107.9	0.5	97.0	97.0	0.0	101.9	101.6	0.3	107.0	106.4	0.6
	4.0	101.3	101.4	-0.1	106.3	105.8	0.5	111.5	111.0	0.5	100.0	99.9	0.1	104.9	104.7	0.2	110.0	109.8	0.2
	4.5	104.3	104.5	-0.2	109.4	109.4	0.0	114.5	114.6	0.0	102.9	103.2	-0.3	107.9	108.1	-0.2	113.0	113.3	-0.3
	5.0	107.2	107.8	-0.6	112.4	112.6	-0.2	117.6	117.9	-0.2	105.8	106.1	-0.3	110.9	111.1	-0.2	116.1	116.1	0.0
	5.5	109.9	110.6	-0.6	115.4	115.5	-0.1	120.7	121.0	-0.2	108.5	109.4	-0.8	113.9	114.6	-0.6	119.2	120.0	-0.6
	6.0	113.8	114.0	-0.2	119.8	119.7	0.1	125.6	125.5	0.1	112.5	112.5	0.0	118.5	118.1	0.3	124.1	123.9	0.2
Weight (kg)	3.0	13.8	13.8	-0.3	15.7	15.8	-0.7	18.1	18.0	0.6	13.3	13.4	-0.7	15.1	15.1	-0.3	17.3	17.4	-0.5
	3.5	14.6	14.6	0.2	16.6	16.5	0.4	19.1	19.1	0.1	14.0	14.1	-0.7	15.9	15.9	0.3	18.1	18.2	-0.7
	4.0	15.4	15.4	-0.1	17.5	17.4	0.6	20.3	20.2	0.4	14.7	14.7	0.1	16.7	16.7	-0.2	19.3	19.3	0.0
	4.5	16.2	16.1	0.4	18.5	18.5	-0.1	21.6	21.5	0.4	15.5	15.4	0.4	17.7	17.7	0.0	20.5	20.5	-0.1
	5.0	16.9	17.0	-0.4	19.5	19.5	0.0	23.0	23.1	-0.3	16.3	16.4	-0.8	18.6	18.7	-0.6	21.6	21.7	-0.4
	5.5	17.7	17.8	-0.4	20.6	20.5	0.4	24.6	24.6	-0.1	17.0	17.1	-0.3	19.7	19.7	-0.1	23.5	23.3	0.7
	6.0	19.0	19.0	-0.2	22.3	22.2	0.3	27.0	27.0	0.1	18.1	18.2	-0.4	21.0	21.1	-0.4	25.0	25.1	-0.5
Chest circum ference (cm)	3.0	49.3	49.8	-0.9	52.3	52.1	0.4	55.5	55.1	0.8	48.4	49.0	-1.3	51.3	51.0	0.6	54.3	54.0	0.5
	3.5	50.1	49.9	0.4	53.1	52.8	0.5	56.3	56.5	-0.3	49.1	49.0	0.1	51.9	52.0	-0.2	55.0	55.0	0.0
	4.0	50.8	51.1	-0.6	53.9	54.2	-0.6	57.3	57.4	-0.2	49.7	50.0	-0.7	52.6	52.4	0.3	55.8	56.0	-0.4
	4.5	51.5	51.7	-0.4	54.7	54.9	-0.4	58.3	58.0	0.6	50.3	50.0	0.5	53.2	53.0	0.4	56.7	57.0	-0.5
	5.0	52.1	51.8	0.6	55.5	55.7	-0.3	59.5	59.6	-0.2	50.8	51.0	-0.4	53.9	54.0	-0.2	57.7	57.2	0.8
	5.5	52.7	53.1	-0.8	56.4	56.2	0.3	60.7	60.3	0.7	51.4	51.8	-0.8	54.6	54.8	-0.3	58.6	58.8	-0.3
	6.0	53.6	54.2	-1.2	57.7	58.0	-0.5	62.8	63.0	-0.4	52.3	53.0	-1.3	55.8	56.0	-0.4	60.0	60.7	-1.1

*[(Fitted data- measured data)/measured data] x 100.

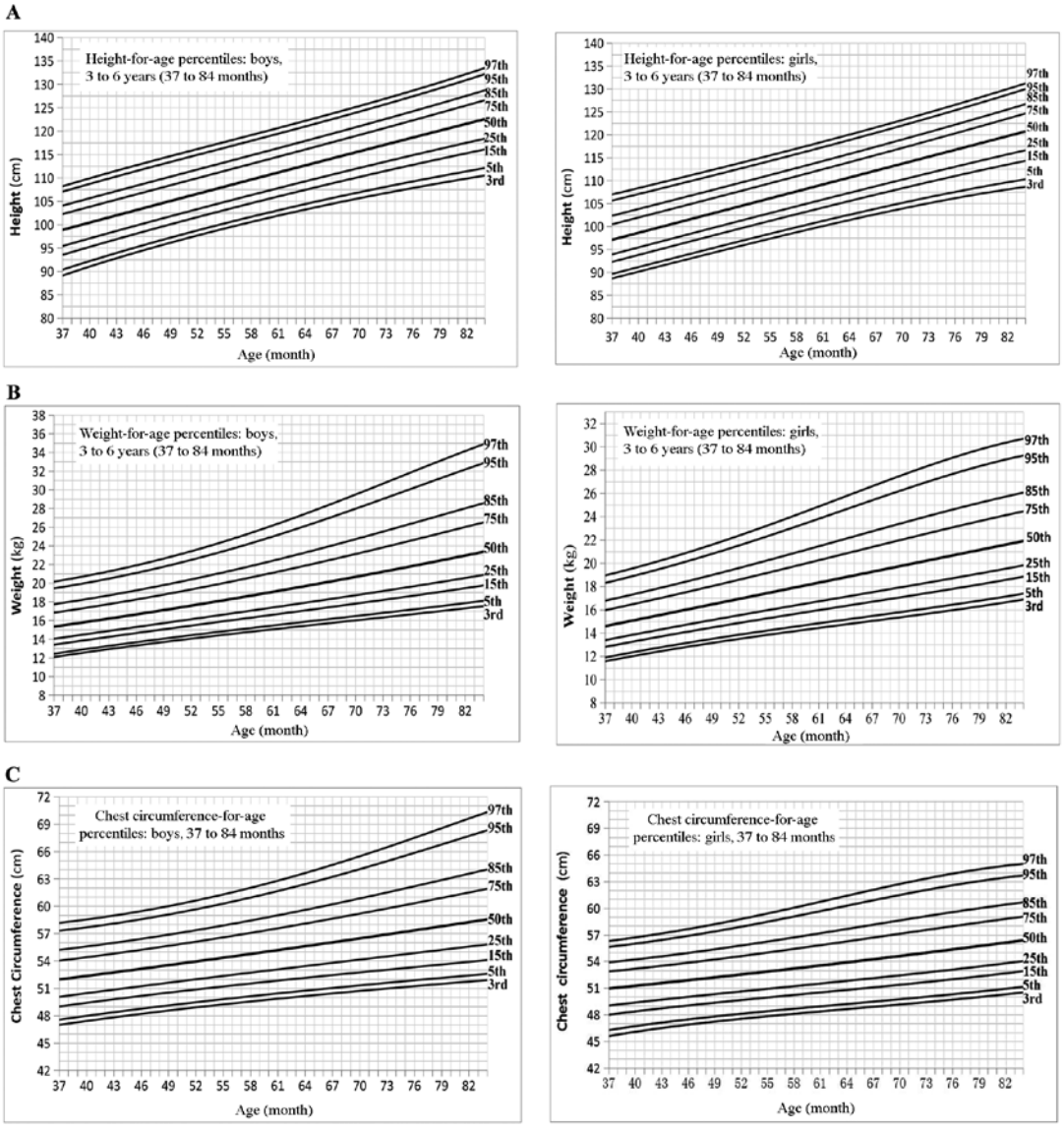

Fig 1-Percentile curves of (A) height-for-age, (B) weight-for-age and (C) chest circumference-for-age of pre-school children 3-6 years of age in China, 2014.

of pre-school children in the age range of 3-6 years covering all 31 provinces in mainland China (General Administration of Sport of China, 2017) and, thus, could be considered widely representative of the whole country. The data showed height had an approximately normal distribution, whereas weight and chest circumference had non-normal distribution, thereby requiring the LMS method of analysis (Table 1),which is applicable to normal and non-normal distribution data. Cole (1990) first established the LMS method to analyze growth curves of body shapes of

Table 3
The comparisons between fitted and frequency distribution of measured height, weight and chest circumference of pre-school children 3-6 years of age in China, 2014.

Years of age	Height (p-value)[a]		Weight (p-value)[a]		Chest circumference (p-value)[a]	
	Male	Female	Male	Female	Male	Female
3.0	0.63	0.69	0.56	0.49	0.41	0.42
3.5	0.75	0.80	0.53	0.57	0.52	0.46
4.0	0.88	0.89	0.69	0.53	0.47	0.59
4.5	0.95	0.93	0.71	0.82	0.60	0.62
5.0	0.79	0.76	0.49	0.79	0.51	0.47
5.5	0.63	0.65	0.62	0.67	0.44	0.45
6.0	0.54	0.65	0.48	0.55	0.38	0.41

[a]Chi-square test.

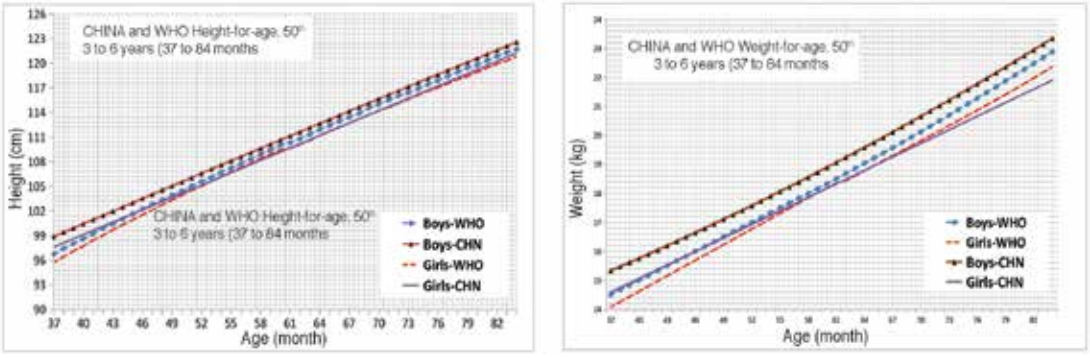

Fig 2-Comparisons of China (this study) with WHO (2006) standards for height-for-age and weight-for-age of pre-school children 3-6 years of age at the 50th percentile.

British children and adolescents enabling the establishment of reference values of normal development standards for European children and adolescents (Cole and Roede, 1999). Thereafter, researchers worldwide adopted this method to develop growth curves, including US CDC (Wei *et al*, 2000) and WHO (2000), In China, the LMS method has been applied to develop growth reference standards for height, weight, chest circumference, BMI, and waist circumference(Lei, 2003; Hui *et al*, 2009). This study is the first to apply the LMS method at a national level.

Growth rates of pre-school children 3-6 years of age were ranked weight > height > chest circumference, indicating the increase in limbs length was greater than that of the chest circumference, and hence the body shapes of children were becoming more slender. The percentile curve spacing of height increased slightly with age, but the increase in rate was small, and the curve was approximately

parallel. The spacing between the percentiles of weight and chest circumference increased significantly with age, especially above the 50th percentile, indicating increase in percent overweight and obesity of children 5-6 years old, but this finding needs further verification.

The differences between China and WHO (2006) standards for height and weight could be attributed to the large differences in the samples properties, such as race, nature, and socioeconomic environment, of China and WHO. The data in the current study were collected in 2014 while those of the WHO were obtained around 2000. WHO (2006) data do not have chest circumference standard for 3 to 6 years old children. Chest circumference measurement is an important parameter to assess development of respiratory organ and of body shape. In China reference standards of chest percentiles for fetal and neonatal infants (Huang *et al*, 2017; Xiaoyun *et al*, 2018) and for children <1-18 years of age (Lei *et al*, 2003) have been established using the LMS method. Chest circumference of Chinese children has increased in the past 15 years. For example, in this study at the 50th percentile chest circumference of male children of 3, 4, 5 and 6 years of age was 1.13, 1.53, 1.98, and 1.99 cm larger, respectively than Xi'an standard (Lei *et al*, 2003); and for female children chest circumference was greater by exceeded 1.02, 1.09, 1.33, and 1.34 cm, respectively, indicating improvement in development of the respiratory organs.

In summary, data of height, weight and chest circumference of pre-school children 3-6 years obtained from the 2014 China National Survey of national physical fitness in all provinces of the country's mainland showed skewness in the data of weight and chest circumference, requiring the application of the LMS method to construct percentile reference standards and curve charts of height-, weight- and chest circumference-for-age of the pre-school children. There was good fitness of the constructed curves with the measured values and the curves smoothness was good. As the standard charts of height, weight and chest circumference were generated from a national representative dataset, they can be used to monitor the growth and development of pre-school children in the country. This dataset will also be helpful for early identification of growth abnormalities, disease diagnosis and the approach employed in the study should be encouraged in the field of preventive healthcare.

ACKNOWLEDGEMENTS

The study was supported by Zhejiang province philosophy and social science planning fund (NO.19NDJC061YB). National education science 2018 key subject of the Ministry of Education (NO. DHA18035) and Special fund for basic scientific research operations of the Institute of Sports Science (No.17-16). We thank all participants who took part in the study.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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