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A study of trends in body morphology, overweight, and obesity in Chinese adults aged 40–59 years

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Abstract

Objective To reveal the changing pattern of anthropometry of middle-aged adults aged 40–59 in China from 2000–2020, and to predict the development trend in the next decade, to provide a reference basis for curbing the prevalence of overweight and obesity in them.

Methods A grey GM(1,1) prediction model was established for the cross-sectional data on anthropometric measures of 422,851 adults obtained from five series of national physical fitness surveillance in China.

Results 1) From 2000 to 2020, all anthropometric indicators of middle-aged people aged 40–59 years in China maintained growth, with waist circumference increasing at the highest rate, weight at the second highest rate, and height at the slowest rate; 2) Overweight and obesity rates are increasing rapidly, with an average annual increase of 0.37 percentage points and 0.30 percentage points, with a greater increase for men than for women.

Conclusion Without stronger interventions, overweight and obesity rates among middle-aged adults are likely to continue to increase in the future, and coordinated efforts are needed to slow down the obesity epidemic and improve the physical health of middle-aged adults.

Keywords Anthropometry, Middle-aged adults, Dynamic change, Prediction, GM(1,1) model, Overweight and obesity

Introduction

With China's rapid economic development in the twenty-first century, the living conditions and nutritional status of the population have greatly improved. However, there is a simultaneous problem is overnutrition, which has led to a rapid increase in the detection rate of overweight and obesity [1]. An analysis of Chinese anthropometric measures from 63,449 cases from 2002 to 2019 showed that [2], according to BMI (body mass index), 29.6% of the total sample size in men were overweight and 11.8% were obese, and 30.0% of the total sample size in women were overweight and 14.0% were obese. According to the body fat percentage, the obesity rate was 54.0% in the total sample size of men and 27.2% in the total sample size of women. According to the mean waist circumference, the male 40–59 age group is in the pre-central obesity stage, and about half of the adults in China are overweight or obese in 2019, making China one of the countries with the largest number of overweight or obese people in the world [3]. The development of obesity poses a huge health threat.

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Changes in anthropometric measures as an outward sign of physical health. First of all, middle-aged people between the ages of 40 and 59 are at an excessive stage in their life cycle, they are moving from youth to old age, and their physical functions are going from up to down [4]. Timely understanding of changes in anthropometric measures is an important means of evaluating the physical health of middle-aged people. Secondly, the continuous investigation and research on the anthropometric measures of middle-aged people can reveal the chronological pattern of change in the development of the body, and provide reference materials for "early prevention and early treatment" to curb the epidemic trend of overweight and obesity-induced chronic diseases. When we look at the existing studies on the anthropometric measures of Chinese middle-aged people, most of them are based on cross-sectional surveys of a certain period of time [5], and there are fewer continuous surveys and studies covering the whole of China.

The Chinese government attaches great importance to the physical fitness and health of its citizens and has implemented the National Physical Fitness Surveillance Program (CNPFS) since 2000, establishing an institutional and systematic system for monitoring the physical fitness of the whole population on a five-year cycle. These surveys have provided important data for the study of the anthropometric and health of middle-aged people in China, but there has been no study using the CNPFS data to explore the changing patterns of anthropometric and overweight and obesity among middle-aged people between the ages of 40 and 59.

Grey GM(1,1) model is an effective model for constructing the long-term changes of anthropometric measures in middle-aged Chinese. The current time series research methods are mainly based on comparative analysis or linear regression analysis [6, 7], which are less effective in exploring the changing pattern of "fewer data". The gray model GM(1,1) is an effective model for fuzzy description of the development of things, since its creation in 1982 [8], it has been widely used in a variety of fields such as medicine, economy, and society. The model can use less time series data to achieve high-precision prediction, the model can be modeled with "fewer data" [9], which is more suitable for the characteristics of the annual series data in this study.

In the present study, based on a series of anthropometric measures by China's five national physical fitness surveys, we established a GM(1,1) model of the anthropometric measures of adults aged 40–59 years old by gender and age group, and exploring the characteristics of anthropometric measures changes and development trends of Chinese adults since 2000, with the aim of improving the physical fitness and health level of adults in China, and curbing the trend of overweight and obesity.

Materials and methods

Research subjects

The study population was middle-aged people aged 40–59 years in China. The data were obtained from five consecutive cross-sectional surveys of the Chinese National Physical Fitness Surveillance (CNPFS) [10–14]. The samples were drawn using the principle of stratified random cluster sampling and were divided into two types of samples according to gender. The sample sizes of middle-aged people aged 40–59 in each year were as follows: 74,521 in 2000 (37,718 men and 36,803 women), 80,880 in 2005 (40,249 men and 40,631 women), 76,642 in 2010 (38,564 men and 38,078 women), 68,880 in 2014 (34,354 men and 34,526 women), and 121,928 in 2020, for a total of 422,851 people.

Measurement method

All tests were completed at the same location using the same brand of testing equipment and the same testing method, and the subjects were all of sound development, without congenital or hereditary diseases (e.g. congenital heart disease, paralysis, deafness, dementia, mental anomalies, developmental delays, etc.), and without contraindications to exercise. The indicators for the study were the anthropometric component of the five Chinese National Physical Fitness Surveillance from 2000 to 2020, including height, weight, waist circumference, hip circumference, body mass index (BMI), and waist-hip ratio (WHR). The test methods for each indicator are as follows:

The height is measured by a calibrated height measuring instrument, with the subject standing on the base plate of the height tester with bare feet and back to the column, torso naturally straight, eyes looking straight ahead, the upper edge of the ear screen and the lowest point of the lower edge of the eye sockets in a horizontal position, upper limbs naturally drooping, head straight, both legs straight, both heels together, the heel of the foot, the sacral part and the two scapulae in contact with the column, in a straight line, at which time the tester will slide the horizontal pressure plate along the measuring column downwards to the top of the subject's head and lock the height measurement value in centimeters. weight was measured in kilogram (kg) using a calibrated scale, with the subject wearing shorts or close-fitting thin pants, barefoot, standing naturally in the center of the weight sensor pedal, and starting the measurement after keeping the body steady. waist and hip circumference were measured by a nylon tape measure, with the tester facing the subject, waist circumference was measured perimeter at a point of 0.5–1 cm above the umbilicus, while keeping

the measuring tape horizontal (the thickest point of the waist was available for obese persons), and hip circumference was measured perimeter horizontally at the part of the most protruding gluteus maximus muscle in centimeters. Body mass index (BMI) = weight divided by height squared (kg/m^2), according to China's BMI classification assessment standards (24.0 ≤ BMI < 28.0 is overweight, BMI ≥ 28.0 is obese). Waist-hip ratio = Waist circumference divided by hip circumference. Results accurate to 0.1.

Research method

The main research method is the GM(1,1) grey modeling method. The data obtained from the previous monitoring were used as time series data to construct a grey GM(1,1) model, then analyze the dynamic changes of the body morphology indicators during the 20 years from 2000 to 2020, and finally predict the values of each indicator in 2025 and 2030.

Introduction to the grey model GM (1,1)

Gray system theory is a kind of uncertainty system prediction theory created by Professor Deng Julong [8] focusing on the research of probability statistics, fuzzy mathematics makes it difficult to solve the "small sample", "poor information", and "uncertainty" problem. Grey dynamics model (grey dynamics model, GM) is through the known sequence generation, modeling to extract valuable information, to achieve the operation of the system, and the evolution of the law of accurate and effective grasp, GM (1,1) is one of the most important models. Due to its relatively low data quality requirements for structural reasons, it is characterized by a small number of required samples and high fitting accuracy and has been widely used in many fields such as agriculture, industry, society, economy, transportation, water conservancy, meteorology, environment, medical science, education, sports, and so on [15, 16]. The model parameter development coefficient |a| ≤0.3 can be used for short-term and medium- to long-term prediction with high accuracy [17]. The fluctuating characteristics of longitudinal changes in the body shape sequence data obtained from the successive monitoring of China's national physique are in line with the conditions of the gray theoretical modeling, and the method of checking the prediction accuracy of the gray model is also very perfect, and a better prediction effect can be obtained.

Model building process

The main process of constructing the grey mean GM(1,1) model is as follows: generating isochronous time series data, establishing the GM(1,1) model, testing the model, and deriving the fitted and predicted values. The modeling process is illustrated by the example of "height of men aged 40–44 years":

The five nationally monitored heights in 2000, 2005, 2010, 2014, and 2020 were 168.3 cm, 168.5 cm, 168.6 cm, 169.0 cm, and 169.4 cm, respectively. According to the isochronous modeling requirements, 169.0 cm in 2014 was adjusted to 169.1 cm in 2015 by interpolation [18]. The principle of GM(1,1) model suggests [19] that the first data are not involved in determining the predicted values of the model, and an arbitrary value can be added before the series in order to involve as many years of raw data as possible in the modeling. Therefore, in this study, a number"10"is added at the beginning of the series data, and the modeling vector is [10, 168.3, 168.5, 168.6, 169.1, 169.4], as follows:

(1) 2014 values adjusted to 2015 values:

$$X^{(0)}(5) = X^{(0)}(4) + \frac{5}{4} \times \left[X^{(0)}(5) - X^{(0)}(4)\right] = 168.6 + \frac{5}{4} \times (169.0 - 168.6) = 169.1$$

(2) The initial vector is:

$$X^{(0)}(m) = 10\ 168.3\ 168.5\ 168.6\ 169.1\ 169.4$$

(3) Accumulating Generation Operator (1-AGO) for the initial vector:

$$X^{(1)}(m) = [10\ 178.3\ 346.8\ 515.4\ 684.5\ 853.9]$$

(4) 1-AGO generates the adjacent mean of the sequence:

$$W^{(0)}(m) = [94.15\ 262.55\ 431.10\ 599.90\ 769.10]$$

(5) Generate the coefficient matrix B and Y (n):

$$B = \begin{bmatrix} -W^{(1)}(2) & 1 \\ -W^{(1)}(3) & 1 \\ -W^{(1)}(4) & 1 \\ -W^{(1)}(5) & 1 \\ -W^{(1)}(6) & 1 \end{bmatrix} = \begin{bmatrix} -94.15 & 1 \\ -262.55 & 1 \\ -431.10 & 1 \\ -599.95 & 1 \\ -769.20 & 1 \end{bmatrix},$$

$$Y(n) = [X^{(0)}(2), X^{(0)}(3), \ldots, X^{(0)}(n)] = 168.3\ 168.5\ 168.6\ 169.1\ 169.4$$

(6) Least squares method to solve for the grey model development coefficients a and constant b:

Table 1 Statistical list of the relative error between predicted simulated and original value in this study

Year	Original value	Fit values, Predicted values	Residual	Precision of fitting
2000	168.3	168.2	0.1	99.9%
2005	168.5	168.5	0.0	99.9%
2010	168.6	168.8	-0.2	99.9%
2015	169.1	169.1	0.0	99.9%
2020	169.4	169.3	0.1	99.9%
2025	/	169.6	/	/
2030	/	169.9	/	/

Table 2 A list of testing standards for the grey forecasting model in this study

Model fit rank	Ratio C of mean squared variance	Small error probability P	Average relative accuracy
Excellent (level 1)	< 3.5e-0.1	> 9.5e-0.1	> 99.0%
Good (level 2)	< 5.0e-0.1	> 8.0e-0.1	> 95.0%
Qualified (Level 3)	< 6.5e-0.1	> 7.0e-0.1	> 90.0%
Nonconforming standard (Level 4)	< 8.0e-0.1	> 6.0e-0.1	≤ 90.0%

$$\begin{pmatrix} a \\ b \end{pmatrix} = \left(B^T B\right)^{-1} B Y^T = \begin{pmatrix} -0.00166 \\ 168.06409 \end{pmatrix}$$

(7) Predictive modeling equations:

$$Y^{(0)}(m) = (1 - e^{a})\left(X^{(0)}(1) - \frac{b}{a}\right)e^{-a(m-1)} = 167.94129e^{-0.00166(m-1)}$$

(8) Cumulative reduction to 2025 projections:

$$\hat{Y}^{(0)}(7) = \hat{Y}^{(1)}(7) - \hat{Y}^{(1)}(6) = 169.62189$$

(9) The average simulated relative error was calculated to be 0.04258%, the average relative accuracy was 99.96%, and the mean–variance ratio C was 0.23. For reference, the prediction level can be known as Level 1 (Table 1, Table 2).

Research result

Sample characteristics

The anthropometric indicators in this study are height, weight, waist circumference, hip circumference, BMI and waist-hip ratio. From 2000 to 2020, in terms of the trend of chronological change, all indicators of middle-aged Chinese men and women have increased to different degrees, with waist circumference increasing the fastest, weight the next, and height the slowest; in terms of gender, the increase in each indicator is greater for men than for women. (Fig. 1).

Dynamics and projections of indicators, 2000–2020

Among them, the model parameter development coefficient "a" reflects the intrinsic development trend of the time series data, "a" is "negative" indicates that the series has an increasing trend, "a" is "positive" indicates that the series has a decreasing trend." The absolute value of "a" indicates the magnitude of increase or decrease, the

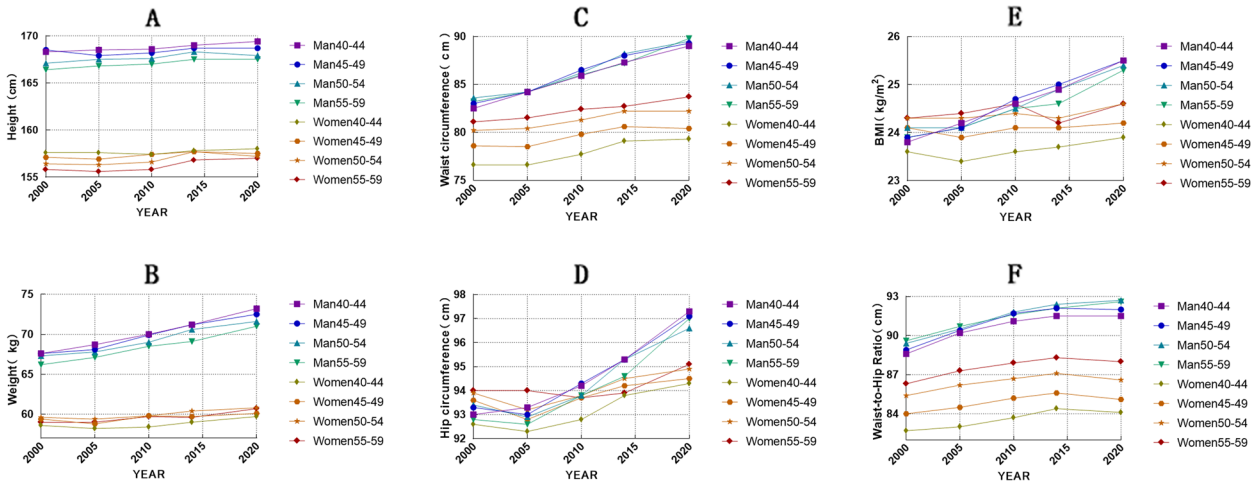

Fig. 1 Trends in anthropometric indicators of middle-aged people in China, 2000–2020

smaller the absolute value of "a" indicates the smaller the magnitude of change in the time series, and vice versa [17]. The results of the study show that the development coefficient "a" is negative for all indicators, indicating an increasing trend in all indicators since 2000.

Height

According to the relevant parameters of the height grey model GM (1, 1), the average error of the fitting curve for each age is 0.04% to 0.24%, and the accuracy of the models is above 99.50%, indicating that the established models are highly effective. (1) Vertical comparison aspects: From 2000 to 2020, the height of men increased by 1.00 to 1.20 cm in all age groups, with an average increase of 1.10 cm (an annual increase of 0.03%); and the height of women increased by 0.40 to 1.50 cm, with an average increase of 1.00 cm (an annual increase of 0.03%). Comparison of age groups, the magnitude of increase for men was 55–59 years old, 50–54 years old, 40–44 years old, 45–49 years old, and for women was 55–59 years old, 50–54 years old, 45–49 years old, 40–44 years old, with the increase in the older age groups being greater than that in the younger age groups. (2) Future projections: from 2020 to 2030, the height of middle-aged people in China will continue to grow, with an average annual increase of 0.03% for men and women in all age groups, which is the same as that from 2000 to 2020 (Table 3).

Weight

According to the relevant parameters of the weight grey model GM (1, 1), the average error of the fitting curve for each age is 0.20%-0.47%, and the accuracy of the models is above 99.50%, indicating that the established models are highly effective. (1)Vertical comparison aspects: From 2000 to 2020, the weight of middle-aged men aged 40–59 increased by 4.70–5.60 kg, with an average increase of 5.10 kg (an annual increase of 0.37%); the weight of women increased by 0.90–1.60 kg, with an average increase of 1.30 kg (an annual increase of 0.11%), and the weight of men increase was greater than women. Comparison of age groups, the increase for men was in the order of 40–44 years old, 45–49 years old, 55–59 years old, 50–54 years old; the increase for women was in the order of 55–59 years old, 50–54 years old, 40–44 years old, 45–49 years old. The weight of men's gain was greater in the younger than in the older age groups, while the opposite was true for women. (2)Future projections: From 2020 to 2030, the weight of middle-aged people in China will continue to increase, with an average annual increase of 0.39% and 0.15% for men and women, respectively, in all age groups, which is higher than that of the period from 2000 to 2020 (Table 4).

Waist circumference

According to the relevant parameters of the waist measurement grey model GM (1, 1), the average error of the fitting curve for each age is 0.13%-0.50%, and the accuracy of the models is above 99.50%, indicating that the established models are highly effective. (1) Vertical comparison aspects: From 2000 to 2020, the waist circumference of middle-aged men aged 40–59 increased by 6.50–6.70 cm, with an average increase of 6.60 cm (an annual increase of 0.37%); the waist

Table 3 Parameters, fitting and predicted values of GM (1, 1) for height of middle-aged people aged 40–59 years in China, 2000–2030

Parameter and Year	man				Women			
	40–44 years old	45–49 years old	50–54 years old	55–59 years old	40–44 years old	45–49 years old	50–54 years old	55–59 years old
$10^{-3}a$[a]	-1.7	-1.5	-1.6	-1.8	-0.7	-1.1	-2.1	-2.5
b[b]	168.1	167.7	167.1	166.3	157.4	156.9	156.1	155.3
Fitting error(%)	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
2000	168.2	167.8	167.2	166.5	157.5	157.0	156.2	155.5
2005	168.5	168.0	167.5	166.8	157.6	157.2	156.6	155.9
2010	168.7	168.3	167.7	167.1	157.7	157.3	156.9	156.3
2015	169.0	168.5	168.0	167.4	157.8	157.5	157.2	156.6
2020	169.3	168.8	168.2	167.7	157.9	157.7	157.6	157.0
2025	169.6	169.1	168.5	168.0	158.0	157.9	157.9	157.4
2030	169.9	169.3	168.7	168.2	158.1	158.0	158.2	157.8
2020–2000[c]	1.1(0.7%)	1.0(0.6%)	1.0(0.6%)	1.2(0.7%)	0.4(0.3%)	0.7(0.4%)	1.4(0.9%)	1.5(1.0%)
2030–2020[d]	0.6(0.4%)	0.5(0.3%)	0.5(0.3%)	0.5(0.3%)	0.2(0.1%)	0.3(0.2%)	0.6(0.4%)	0.8(0.5%)

Annotation: [a]a is the model development coefficient

[b] b is the amount of gray effect

[c] 2020–2000 is the difference between the model fit in 2020 and 2000, with growth rates from 2000 to 2020 in parentheses, and [d] 2030–2020 is the same as above

Table 4 Parameters, fitting and predicted values of GM (1, 1) for weight of middle-aged people aged 40–59 years in China, 2000–2030

Parameter and Year	man				Women			
	40–44 years old	45–49 years old	50–54 years old	55–59 years old	40–44 years old	45–49 years old	50–54 years old	55–59 years old
$10^{-3}a$[a]	-20.0	-18.9	-17.0	-17.3	-5.3	-3.9	-5.8	-6.7
b[b]	66.7	66.7	66.4	65.5	58.0	59.0	59.1	58.6
Fitting error(%)	0.2	0.3	0.5	0.2	0.5	0.4	0.3	0.4
2000	67.4	67.3	67.0	66.1	58.2	59.1	59.3	58.8
2005	68.8	68.6	68.1	67.2	58.5	59.3	59.7	59.2
2010	70.2	69.9	69.3	68.4	58.8	59.6	60.0	59.6
2015	71.6	71.2	70.5	69.6	59.1	59.8	60.4	60.0
2020	73.0	72.6	71.7	70.8	59.4	60.0	60.7	60.4
2025	74.5	74.0	73.0	72.0	59.7	60.3	61.1	60.8
2030	76.1	75.6	74.4	73.4	60.4	60.7	61.6	61.4
2020–2000[c]	5.6(8.3%)	5.3(7.9%)	4.7(7.0%)	4.7(7.1%)	1.2(2.1%)	0.9(1.5%)	1.4(2.4%)	1.6(2.7%)
2030–2020[d]	3.1(4.2%)	3.0(4.1%)	2.7(3.8%)	2.6(3.7%)	1.0(1.7%)	0.7(1.2%)	0.9(1.5%)	1.0(1.7%)

Annotation: [a]a is the model development coefficient

[b] b is the amount of gray effect

[c] 2020–2000 is the difference between the model fit in 2020 and 2000, with growth rates from 2000 to 2020 in parentheses, and [d] 2030–2020 is the same as above

circumference of women increased by 2.40–3.30 cm, with an average increase of 2.70cm (an annual increase of 0.17%), and the increase in the rate of increase for men was greater than that for women. Comparison of age groups, the magnitude of increase for men was in the order of 45–49 years old, 40–44, 55–59 years old, 50–54 years old, and for women in the order of 40–44 years old, 55–59 years old, 45–49 years old and 50–54 years old, with the increase in the younger age groups being greater than that older age groups. (2) Future projections: From 2020 to 2030, the waist circumference of middle-aged people in China will continue to grow, with an average annual increase of 0.39% and 0.18% for males and females in all age groups, respectively, which is higher than that of the period from 2000 to 2020 (Table 5).

Table 5 Parameters, fitting and predicted values of GM (1, 1) for waist circumference of middle-aged people aged 40–59 years in China, 2000–2030

Parameter and Year	Man				Women			
	40–44 years old	45–49 years old	50–54 years old	55–59 years old	40–44 years old	45–49 years old	50–54 years old	55–59 years old
$10^{-3}a$[a]	-19.2	-19.5	-18.9	-19.2	-10.5	-7.4	-7.4	-7.9
b[b]	81.8	82.2	82.4	82.1	75.9	78.2	79.8	80.7
Fitting error(%)	0.1	0.3	0.5	0.3	0.5	0.5	0.3	0.1
2000	82.6	83.0	83.2	82.9	76.3	78.4	80.1	81.0
2005	84.2	84.6	84.8	84.5	77.1	79.0	80.7	81.6
2010	85.8	86.2	86.4	86.1	77.9	79.6	81.3	82.3
2015	87.5	87.9	88.1	87.8	78.7	80.2	81.9	82.9
2020	89.2	89.7	89.7	89.5	79.6	80.8	82.5	83.6
2025	90.9	91.4	91.4	91.2	80.4	81.4	83.1	84.3
2030	92.6	93.2	93.5	93.2	81.5	82.1	83.8	85.0
2020–2000[c]	6.6(8.0%)	6.7(8.1%)	6.5(7.8%)	6.6(8.0%)	3.3(4.3%)	2.4(3.1%)	2.4(3.0%)	2.6(3.2%)
2030–2020[d]	3.4(3.8%)	3.5(3.9%)	3.8(4.2%)	3.7(4.1%)	1.9(2.4%)	1.3(1.6%)	1.3(1.6%)	1.4(1.7%)

Annotation: [a] a is the model development coefficient

[b] b is the amount of gray effect

[c] 2020–2000 is the difference between the model fit in 2020 and 2000, with growth rates from 2000 to 2020 in parentheses, and [4] 2030–2020 is the same as above

Hip circumference

According to the relevant parameters of the hip measurement grey model GM (1, 1), the average error of the fitting curve for each age is 0.31%-0.57%, and the accuracy of the models is above 99.00%, indicating that the established models are highly effective. (1) Vertical comparison aspects: From 2000 to 2020, hip circumference for middle-aged men aged 40 to 59 increased by 3.70 to 4.40 cm, with an average increase of 4.10 cm (an annual increase of 0.22%); for women, it increased by 1.20 to 2.10 cm, with an average increase of 1.50 cm (an annual increase of 0.08%), the hip circumference of men increase was greater than women. Comparison of age groups, the magnitude of increase for men was in the order of 40–44 years old, 55–59 years old, 45–49 years old, 50–54 years old, and for women it was in the order of 40–44 years old, 50–54 years old, 45–49 years old, 55–59 years old, and the increase in hip circumference of women had a tendency to decrease with the increase in age. (2) Future projections: From 2020 to 2030, the hip circumference of middle-aged people in China will continue to grow, with an average annual increase of 0.26% and 0.12% for men and women in all age groups, respectively, which is higher than that of the period from 2000 to 2020 (Table 6).

BMI

According to the relevant parameters of the BMI grey model GM (1, 1), the average error of the fitting curve for each age is 0.17%-0.47%, and the accuracy of the models is above 99.50%, indicating that the established models are highly effective. (1) Vertical comparison aspects: From 2000 to 2020, the BMI of middle-aged men aged 40–59 increased by 1.30–1.60 kg/m2, with an average increase of 1.50 kg/m^2 (an annual increase of 0.30%); the BMI of women increased by 0.10–0.30 kg/m^2, with an average increase of 0.20 kg/m^2 (an annual increase of 0.04%), the BMI of men increase was greater than women. Comparison of age groups, for men, the increase was in the order of 40–44 years old, 45–49 years old, 50–54 years old, 55–59 years old; for women, it was in the order of 40–44 years old, 50–54 years old, 55–59 years old, 45–49 years old, with a higher increase in the younger age groups. (2) Future projections: In 2020–2030, the BMI of middle-aged people in China will continue to grow, with an average annual increase of 0.33% and 0.07% for men and women in all age groups, respectively, which is higher than that in the period 2000–2020 (Table 7).

Waist-hip ratio

According to the relevant parameters of the waist-hip ratio grey model GM (1, 1), the average error of the fitting curve for each age is 0.23%-0.52%, and the accuracy of the models is above 99.50%, indicating that the established models are highly effective. (1) Vertical comparison aspects: From 2000 to 2020, the waist-hip ratio of middle-aged men aged 40–59 will increase by 2.80 to 3.40, with an average increase of 3.10 (or 0.17% per year); and the waist-hip ratio of women will increase by 1.40 to 1.80, with an average increase of 1.60 (or 0.09% per year),

Table 6 Parameters, fitting and predicted values of GM (1, 1) for waist circumference of middle-aged people aged 40–59 years in China, 2000–2030

Parameter and Year	Man				Women			
	40–44 years old	45–49 years old	50–54 years old	55–59 years old	40–44 years old	45–49 years old	50–54 years old	55–59 years old
10^{-3}a[a]	-11.6	-10.8	-9.8	-11.2	-5.6	-3.5	-3.7	-3.1
b[b]	92.0	92.1	92.2	91.6	91.9	93.0	93.2	93.3
Fitting error(%)	0.4	0.4	0.5	0.6	0.4	0.3	0.4	0.5
2000	92.5	92.6	92.7	92.1	92.2	93.1	93.4	93.4
2005	93.6	93.6	93.6	93.2	92.7	93.4	93.7	93.7
2010	94.7	94.6	94.5	94.2	93.2	93.8	94.1	94.0
2015	95.8	95.7	95.4	95.3	93.7	94.1	94.5	94.3
2020	96.9	96.7	96.4	96.4	94.3	94.4	94.8	94.6
2025	98.0	97.8	97.3	97.4	94.8	94.8	95.2	94.9
2030	99.5	99.3	98.8	99.0	95.6	95.4	95.9	95.6
2020–2000[c]	4.4(4.8%)	4.1(4.4%)	3.7(4.0%)	4.3(4.7%)	2.1(2.3%)	1.3(1.4%)	1.4(1.5%)	1.2(1.3%)
2030–2020[d]	2.6(2.7%)	2.6(2.7%)	2.4(2.5%)	2.6(2.7%)	1.3(1.4%)	1.0(1.1%)	1.1(1.2%)	1.0(1.1%)

Annotation: [a] a is the model development coefficient

[b] b is the amount of gray effect

[c] 2020–2000 is the difference between the model fit in 2020 and 2000, with growth rates from 2000 to 2020 in parentheses, and [d] 2030–2020 is the same as above

Table 7 Parameters, fitting and predicted values of GM (1, 1) for waist circumference of middle-aged people aged 40–59 years in China, 2000–2030

Parameter and Year	Man				Women			
	40–44 years old	45–49 years old	50–54 years old	55–59 years old	40–44 years old	45–49 years old	50–54 years old	55–59 years old
$10^{-3}a$[a]	-16.7	-16.3	-13.9	-13.5	-3.8	-1.3	-2.5	-1.6
b[b]	23.6	23.6	23.8	23.7	23.4	24.0	24.2	24.3
Fitting error(%)	0.2	0.4	0.5	0.4	0.4	0.4	0.3	0.5
2000	23.8	23.8	23.9	23.8	23.5	24.0	24.3	24.3
2005	24.2	24.2	24.3	24.1	23.5	24.0	24.3	24.4
2010	24.6	24.6	24.6	24.5	23.6	24.1	24.4	24.4
2015	25.0	25.0	24.9	24.8	23.7	24.1	24.4	24.5
2020	25.4	25.4	25.3	25.1	23.8	24.1	24.5	24.5
2025	25.9	25.8	25.6	25.5	23.9	24.2	24.6	24.5
2030	26.3	26.3	26.1	25.9	24.1	24.3	24.6	24.6
2020–2000[c]	1.6(6.7%)	1.6(6.7%)	1.4(5.9%)	1.3(5.5%)	0.3(1.3%)	0.1(0.4%)	0.2(0.8%)	0.2(0.8%)
2030–2020[d]	0.9(3.5%)	0.9(3.5%)	0.8(3.2%)	0.8(3.2%)	0.3(1.3%)	0.2(0.8%)	0.1(0.4%)	0.1(0.4%)

Annotation: [a] a is the model development coefficient;

[b] b is the amount of gray effect;

[c] 2020–2000 is the difference between the model fit in 2020 and 2000, with growth rates from 2000 to 2020 in parentheses, and [d] 2030–2020 is the same as above

and the increase in the waist-hip ratio of men will be greater than that of women. Comparisons by age group, for men, the magnitude of the increase was in the order of 50–54 years old, 45–49 years old, 55–59 years old, 40–44 years old, and for women, in the order of 40–44 years old, 55–59 years old, 45–49 years old, 50–54 years old. (2) Future projections: In the period 2020–2030, the average annual increases of Chinese middle-aged men and women in all age groups will be 0.14% and 0.0.7%, respectively, which are lower than those in the period 2000–2020 (Table 8).

Overweight and obesity rates

The results of the National Physical Fitness Surveillance showed that [10–14], from 2000 to 2020, the overweight and obesity rates of Chinese adults was increased

Table 8 Parameters, fitting and predicted values of GM (1, 1) for the waist-hip ratio of middle-aged people aged 40–59 years in China, 2000–2030

Parameter and Year	Man				Women			
	40–44 years old	45–49 years old	50–54 years old	55–59 years old	40–44 years old	45–49 years old	50–54 years old	55–59 years old
$10^{-3}a$[a]	-7.9	-8.8	-9.5	-8.3	-5.1	-4.0	-3.9	-5.0
b[b]	88.8	89.1	89.2	89.5	82.5	84.1	85.6	86.5
Fitting error(%)	0.5	0.5	0.3	0.2	0.3	0.4	0.4	0.4
2000	89.2	89.5	89.7	89.8	82.7	84.2	85.7	86.7
2005	89.9	90.2	90.5	90.6	83.2	84.6	86.1	87.1
2010	90.6	91.0	91.4	91.3	83.6	84.9	86.4	87.6
2015	91.3	91.8	92.3	92.1	84.0	85.2	86.8	88.0
2020	92.0	92.6	93.1	92.9	84.5	85.6	87.1	88.4
2025	92.7	93.4	94.0	93.7	84.9	85.9	87.4	88.9
2030	93.1	93.9	94.7	94.3	85.3	86.1	87.5	89.1
2020–2000[c]	2.8(3.1%)	3.1(3.5%)	3.4(3.8%)	3.1(3.5%)	1.8(2.2%)	1.4(1.7%)	1.4(1.6%)	1.7(2.0%)
2030–2020[d]	1.1(1.2%)	1.3(1.4%)	1.6(1.7%)	1.4(1.5%)	0.8(0.9%)	0.5(0.6%)	0.4(0.5%)	0.7(0.8%)

Annotation: [a] a is the model development coefficient

[b] b is the amount of gray effect

[c] 2020–2000 is the difference between the model fit in 2020 and 2000, with growth rates from 2000 to 2020 in parentheses, and [d] 2030–2020 is the same as above

at an average annual rate of 0.37 percentage points and 0.30 percentage points, with a significant growth trend ($P < 0.01$), Among them, the obesity rate doubled in 2020 compared to 2000, indicating that overweight and obesity have become public health problems that seriously jeopardize the health of Chinese residents. Overweight and obesity rates are projected to increase at an average annual rate of 0.36 percentage points and 0.56 percentage points, respectively, by 2030, and overweight and obesity are still facing a serious growth trend (Table 9).

Discussion

Trends in chronological changes in body morphology among Chinese adults aged 40–59 years

In this study, we found that during the period of 2000–2020, all indicators of anthropometry of Chinese middle-aged people aged 40–59 years old increased to different degrees. The magnitude of the increase in the indicators for men was in the following order: waist circumference, weight, waist-to-hip ratio, hip circumference, BMI, and height; and the increase in the indicators for women was in the following order: waist circumference, weight, BMI, hip circumference, waist-to-hip ratio, and height. Comparing the genders, except for height, the increase in all indicators of men was generally greater than women; comparing the age groups, the increase in waist circumference, hip circumference and BMI tended to decrease with age. Projections show that over the next decade, the indicators will continue the growth trend of the previous 20 years. Minhee Chae also found that the growth rate of adult height was significantly higher in the Chinese population born between 1950 and 1990 [20], with similar findings to the present study. A survey of the average height of people born between 1896 and 1996 in 200 countries/regions also shows that there has been a general trend of growth in adult height globally over the past century, with the most pronounced growth in East Asia and Central and Eastern Europe [21]. However, this trend varies significantly across countries and regions, and in high-income Western countries, height growth has already stagnated [22]. Therefore, from the long-term trend, China's future height growth rate may also slow down or even stagnate.

Changes in the growth of anthropometry are influenced by a number of factors. In addition to genetic factors, factors such as socio-economic, nutritional status and health level have an important impact on growth and development. Since China's accession to the World Trade Organization (WTO), per capita GDP has risen from 7,942 yuan in 2000 to 72,447 yuan in 2020 [23], an increase of 9.10 times, and economic development has significantly improved the nutritional status and health of the population. A study of geographic differences in height among young men from 45 countries of European origin showed that nutritional levels accounted for much of the variation in adult height [24], especially high-protein foods such as milk, pork, fish, and wheat. Jessica M Perkins' study of height development in adults suggests that changes in height not only reflect growth and development, but are also associated with a variety of health problems and are a potential tool for monitoring health status [25].Children born in a community-based intervention that provided nutritional supplements during pregnancy and early childhood were 14 mm taller than the control group and had a reduced risk of cardiovascular disease as they entered adolescence, according to a trial in India [26]. Changes in the anthropometry of Chinese adults show a positive trend in their nutritional and health status.

Trends and causes of chronological changes in overweight and obesity among adults aged 40–59 years in China

Trends in overweight and obesity over time

The results of this study show that Chinese adults' waist circumference, body weight, and BMI are growing significantly, and overweight and obesity rates are increasing at a faster rate each year, with projections showing that they will maintain a higher rate of growth in the next decade. Related studies have also found similar conclusions, for example, Jinchen Xie found that the prevalence of overweight and obesity among Chinese adults increased from 20.65% and 3.10% in 1993 to 55.33% and 19.26% in 2021, representing a 2.68 and 6.21-fold increase [27]. The World Obesity Atlas 2024, published by the World Obesity [28], shows that the obesity rate among Chinese adults is expected to grow at an annual rate of 5.40% from

Table 9 Overweight and obesity rates among Chinese adults[a], 2000–2030

Project	2000	2005	2010	2014	2020	2025[b]	2030[c]	2020–2000[d]	2030–2020[e]
Overweight rate	29.1	29.1	32.1	32.7	35.0	36.7	38.6	5.9*	3.6*
Obesity rate	7.3	8.0	9.9	10.5	14.6	16.9	20.2	7.3*	5.6*

Annotation: [a]The range of detection rates includes all adults aged 20–59 years in China

[b] 2025 and [c] 2030 are the predicted values from the gray GM(1,1) model

[d] 2020–2000 and [e] 2030–2020 are the differences between years

* $P < 0.01$

2020 to 2035.The study also found that globally the prevalence of overweight and obesity is projected to increase from 38.00% in 2020 to over 50.00% in 2035. Therefore, China and the world are facing the grim reality of an obesity epidemic, and curbing the growth of overweight and obesity remains an important task for the future.

Reasons for the increase in overweight and obesity over the years

First, economic development has led to changes in the dietary structure of the Chinese population. The increase in global trade and the accelerated development of food industry and agriculture have resulted in an unprecedented food surplus, causing the dietary patterns of Chinese residents to shift from subsistence to diversification to calorie surplus [29]. According to statistics, between 1991 and 2015, the average energy intake of Chinese adults from total carbohydrates decreased from 62.60% to 50.60%, while the average energy intake of total proteins increased from 12.60% to 13.10%, and the average energy intake of total fat increased significantly from 24.00% to 35.80% [30]. Decreased intake of cereals and dietary fiber in the dietary structure of the Chinese population and increased intake of foods rich in sugars, fats, refined carbohydrates and animal foods, leading to an increase in the daily energy density of food intake [29].

Decreased physical activity is another important factor in the increase of obesity. Physical labor has gradually been replaced by static labor in the development of society, while the process of urbanization has also led to lifestyle changes. Statistics show that the number of private cars in China was 6.253 million in 2000, and by 2020 it will have grown to 243.93 million, an increase of 39 times [30], and the popularization of private cars has greatly reduced the number of times and distances that nationals walk daily. With the proliferation of electronics, people are spending more time exposed to electronic screens and have less physical strength and willingness to exercise, leading to more sedentary behaviors that are not conducive to metabolism. Both sedentary behavior and relative time spent in exercise are strongly associated with obesity [31].

In addition, sleep and obesity incidence also have a certain correlation, the shorter the sleep time, the higher the risk of obesity [32], middle-aged people have the same time to take care of their families and careers, the reduction of sleep time is also one of the factors triggering obesity.

Reasons for gender differences in the growth of overweight and obesity

In China, the prevalence of overweight obesity is more common in men than in women. First, a larger proportion of men smoke relative to women, and among individuals with a normal BMI, smokers are more likely to suffer from abdominal obesity than nonsmokers [33]. Secondly, socioeconomics also has a variable impact on obesity. In men, there is a positive correlation between education and income and overweight obesity, a phenomenon that may be due to the availability of adequate food and less physically demanding jobs in high socioeconomic status groups [34]. The opposite is true for women [35], who are more aware and sensitive to obesity and body size. Compared to men, women are more susceptible to the social pressure of body shape, defining slimness as a sign of beauty, and women are influenced by society's concepts to produce a stronger willingness to lose weight and stay in shape, whereas society has a greater acceptance of men's body shape [36]. Third, development in childhood can have an impact on health in adulthood [37]. Individuals who grow up in material shortages and chronic nutritional deprivation are prone to accumulate fat mass later in life. Before China's reform and opening up, most families were in a state of material scarcity and high fertility, in which case girls were more likely to be malnourished than boys, due to the preference for male children, and in the context of family food shortages [38]. Within this particular historical, cultural, and developmental context, the nutrition of middle-aged males is superior to that of females in the postnatal setting and is a potential contributor to the increased risk of overweight in adult males.

Reasons for age differences in the growth of overweight and obesity

The results of this study show that the overall obesity growth rate in middle-aged adults is fastest in the 40–49 age group. In studies of birth cohorts and obesity risk, an inverted U-shaped relationship between obesity prevalence and age was observed at every period [39], specifically, overweight prevalence tended to increase until middle age and decline thereafter, with a significantly higher prevalence of overweight in men compared to women [40].

The stage of weight gain in women differs from that of men in that there is a period of growth in the 50–54 age group [41]. Relevant studies have shown that the distribution of body fat in women is affected during menopause, and that menopause is associated with a trend of weight gain, with higher BMI in postmenopausal women [42]. According to statistics, the average age of menopause for Chinese women is about 50 years old [43], which corroborates the results of this study. In addition, the retirement age of Chinese women is 50 years old, and the reduction of work activities after retirement also increases the chance of being overweight and obese [35].

Limitation

First of all, the gray modeling method used in this study is usually based on linear assumptions, which makes it difficult to completely and accurately describe various complex relationships, and at the same time, the prediction of future trends is greatly influenced by the most terminal data, but it does not completely negate the value of this research method. Further research can be conducted in conjunction with other methods. Secondly, this study did not investigate the quantitative and qualitative relationship between the increase in overweight and obesity and related factors, and will further investigate the factors related to curbing the rapid growth of obesity in the future.

Conclusion

From 2000 to 2020, the anthropometry indicators of Chinese middle-aged people have all become a state of growth, and the rapid growth of waist circumference, body weight, BMI and other indicators have led to a clear trend of growth in the overweight rate and obesity rate, and the obesity situation of men is more serious than that of women. Over the next decade, it is expected that the trend of faster growth will continue for all anthropometry indicators, especially waist circumference and body weight. Therefore, both the Government and the public need to pay attention to this phenomenon and take stronger measures to curb its undesirable development trend.

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Authors' contributions

QP conceived and designed the study. CT did the overall trial management, and XC, YL contributed to the study analysis plan and data analysis. All authors contributed to the article and approved the submitted version.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

The National Physical Fitness Surveillance Program (CNPFS) is a survey organized by the General Directorate of Sports of the country, with all participants signing a written informed consent form. The Taizhou College Academic Ethics and Ethical Science Code Committee ruled that no consent was required. The data for this study were openly accessible on the official website of the China Sports Bureau.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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