PUBLIC HEALTH 175 (2019) 54–59

Available online at www.sciencedirect.com

Public Health

journal homepage: www.elsevier.com/puhe

Original Research

Body mass index cut-off points for predicting chronic non-communicable disease should differ by gender and age group

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ARTICLE INFO

Article history:
Received 4 January 2019
Received in revised form
15 April 2019
Accepted 26 June 2019
Available online 6 August 2019

Keywords:
Body mass index
Chronic non-communicable disease
Age
Gender
Receiver operating characteristic curve

ABSTRACT

Objectives: The objective of this study to determine whether body mass index (BMI) in different genders and age groups need different thresholds when predicting chronic non-communicable diseases (CNCDs).

Study design: This is a cross-sectional study.

Methods: Data were obtained from the China Health and Nutrition Survey conducted in 2009. Sequential sample cluster analysis was used to group age according to BMI. Propensity score matching was used to eliminate the influence of age. Receiver operating characteristic curve based on gender and age group was used to evaluate the cut-off values and efficiency of BMI in each group.

Results: A total of 8469 individuals were enrolled in this study. Results of sequential sample cluster analyses showed age was divided into three groups: 18–39, 40–59 and 60–99 years. There were significant differences in the distribution of BMI among the three groups for both males and females ($P < 0.001$). Statistical differences were observed in the distribution of BMI between genders in the 18–39- and 60–99-year-old age groups ($P < 0.001$). For men, the cut-off values of BMI were $\geq$25 kg/m^2, $\geq$24 kg/m^2 and $\geq$23 kg/m^2 in the 18–39, 40–59 and 60–99 years old groups, respectively; for women, the corresponding cut-off points were $\geq$25 kg/m^2, $\geq$23 kg/m^2 and $\geq$25 kg/m^2 in groups.

Conclusions: The thresholds for BMI might be different between gender and age group. In addition, it might not be suitable to determine cut-off values of BMI to predict CNCDs for people aged $\geq$60 years.

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https://doi.org/10.1016/j.puhe.2019.06.018
0033-3506/

Introduction

Body mass index (BMI) is not only used to measure the degree of obesity and nutritional status but can also be correlated with physical indicators of health.[1] It has been proved that people with high BMI values have a higher risk of chronic non-communicable diseases (CNCDs), such as diabetes mellitus, hypertension, hyperlipidaemia and metabolic syndrome.[2] At present, the Chinese standard BMI cut-off points are $\geq$24 kg/m^2 for overweight and $\geq$28 kg/m^2 for obesity; the corresponding international standards are $\geq$25 kg/m^2 and $\geq$30 kg/m^2. However, neither gender nor age are taken into account in these two cut-off points. It has been reported that the distribution of BMI is different between genders[3] and that the relation between BMI and CNCDs changes with increasing age.[4] It should be noted that a positive correlation was found between all-cause mortality and BMI.[5] Recent studies have shown that the effect of BMI on mortality was significantly different among different age groups; for example, in the elderly population, mortality in overweight people was not higher than mortality in people with normal weight.[2]

Furthermore, current Chinese and international standards of BMI were set up in the 1980s. Over the past 30 years, lifestyles have changed greatly with economic and social development. Meanwhile, the distribution of BMI among different genders and age groups has also changed over time.[6] Therefore, it is time to explore new BMI cut-off values for each gender and age group that better represent the current Chinese population. The existing thresholds of BMI were determined according to the all-cause mortality rate of the population.[7] The relation between BMI and prevalence of CNCDs was ‘U’- or ‘J’-shaped, which was similar to the relation between BMI and all-cause mortality.[8,9] However, it should be noted that some causes of death (e.g. poisoning, injury, infection) have little correlation with BMI, and that CNCDs mortality accounted for about 86% of all causes of death.[10] Therefore, BMI may be more closely related with CNCDs than all-cause mortality. It may be more accurate to set thresholds of BMI based on the number of CNCDs; however, to date, there are no studies that have used the number of CNCDs as an outcome variable to determine the specific BMI cut-off values for each gender and age group.

All data were obtained from the China Health and Nutrition Survey (CHNS) in 2009. The age groups were determined according to the distribution of BMI by sequential sample cluster analysis. Based on these age groups and gender, the thresholds and efficiency of BMI as a predicting measure for the number of CNCDs were analysed by receiver operating characteristic (ROC) curves. This study was designed to set special thresholds of BMI for different genders and age groups, which could help guide more targeted prevention, control and intervention of overweight, obesity and CNCDs.

Methods

Data sources

The data of this cross-sectional study was obtained from the CHNS, a study established in 1989. From 1989 to 2011, the CHNS collected data over a total of nine waves in many provinces, including Liaoning, Jiangsu, Shandong, Henan. A stratified, multistage cluster sampling process was used to select samples in each of the provinces. Two cities (one large and one small, usually the provincial capital and a lower-income city) and four counties (stratified by income, one high-, one low- and two middle-income) per province were selected. Within cities, two urban and two suburban communities were randomly selected. Within counties, one community in the capital city and three rural villages were randomly chosen. Twenty households per community were then randomly selected for participation.[11] Biochemical indicators were surveyed only in 2009, so we selected the data from 2009 for analysis. Analyses were conducted in 2017. The inclusion criterion was all adults aged $\geq$18 years. Individuals without demographic and anthropometric indicators were excluded.

Definitions and diagnostic criteria

CHNS anthropometric indicators (both physical and laboratory examinations) were measured by trained examiners following a standard protocol from the World Health Organization (WHO).[12] Height and weight were measured with light clothes and without shoes after emptying the bladder. BMI was calculated as weight (kg) divided by the square of height (m).

Seven CNCDs were considered in this study as follows: (1) hypertension (defined according to the Chinese Guidelines on Prevention and Control of Hypertension);[13] (2) diabetes mellitus (defined according to the WHO);[14] (3) myocardial infarction (defined according to the WHO);[15] and dyslipidemia, including (4) total cholesterol (TC) $\geq$5.2 mmol/L, (5) triglyceride (TG) $\geq$1.7 mmol/L, (6) high-density lipoprotein cholesterol (HDL-C) <1.0 mmol/L and (7) low-density lipoprotein cholesterol (LDL-C) $\geq$3.4 mmol/L (which were all defined according to the guidelines on prevention and treatment of blood lipid abnormality in Chinese adults of 2016).[16] The ‘number of CNCDs’ value was how many of these seven CNCDs people experienced simultaneously.

Statistical analyses

Statistical analyses were conducted with IBM SPSS Statistics 23.0 (SPSS Inc, Chicago, IL) and statistical analysis system (SAS Institute Inc., Cary, NC) Version 9.2. Demographic and anthropometric data of participants were described as means and standard deviation (SD) for quantitative variables and as frequencies for qualitative variables. Sequential sample cluster analysis[17] was used by SAS to group age according to BMI. A Quartile-Quartile (Q-Q) plot was performed to test the distribution of BMI. One-way analysis of variance (ANOVA) or t-test was used to compare the differences in BMI between different groups if the distribution of BMI was a normal distribution; alternatively, a nonparametric test was used for a skewed distribution. Propensity score matching (PSM)[18] was used to eliminate the effect of age on the distribution of BMI between males and females, in which, gender was regarded as the group indicator and age was regarded as the variable to match on, the match tolerance was set at 0 and random seed was set at 1. An ROC curve based on gender and age group was used to evaluate the cut-off values for BMI in each group, in which, the number of CNCDs of each participant was regarded as state variable. Youden's index was used to determine the best cut-off points for BMI. All P-values were 2-tailed, and the level of significance was set at $\alpha = 0.05$.

Results

The characteristics of participants

A total of 8469 individuals aged 18–92 years old were enrolled in this study. There were 3951 (46.7%) males and 4518 (53.3%) females, with an average age of 50.83 ± 15.05 years and an average BMI of 23.38 ± 3.48 kg/m^2. Among these participants, 2570 (30.3%) had hypertension, 663 (7.8%) suffered from diabetes mellitus, 82 (1.0%) had myocardial infarction, and the number of individuals with TC, TG, HDL-C and LDL-C abnormalities were 819, 1605, 2162 and 947, respectively.

Sequential sample cluster of age according to BMI

Subjects were divided into six age groups, spanning 10 years each, except for the first group which included individuals aged 18–29 years old, and those aged >70 years were merged into one group due to the small sample size. Age was orderly clustered according to the average BMI in each group. The results showed that age was divided into three groups according to the inflexion point in the minimum loss function graph for both males and females, and the cut-off values of males and females were the same; the first group was 18–39 years old, the second group was 40–59 years old and the third group was ≥60 years old (see Table 1). A Q-Q plot showed that BMI was approximately a normal distribution. One-way ANOVA was used to compare the differences of BMI between different age groups. Results showed there were significant differences in the distribution of BMI among the three age groups (male: $F = 25.263$, $P < 0.001$; female: $F = 101.520$, $P < 0.001$).

The effect of gender on the distribution of BMI

A total of 3825 males and 3825 females were included after PSM. There was no statistical difference in age distribution between males and females ($t = 0.000$, $P = 1.000$), allowing comparability between groups. There were statistical differences in the distribution of BMI between genders in the 18–39 years age group and the 60–99 years age group ($P < 0.001$); however, no statistical difference was observed in the 40–59 years age group ($P = 0.129$) [Table 2].

Table 1 – The results of sequential sample cluster of age according to BMI.

	Clustering of age groups[a]	First group (years old)	Second group (years old)	Third group (years old)
Total	1-2|3–4|5-6	18–39	40–59	60–99
Male	1-2|3–4|5-6	18–39	40–59	60–99
Female	1-2|3–4|5-6	18–39	40–59	60–99

BMI, body mass index.
[a] 1, 18–29 years old; 2, 30–39 years old; 3, 40–49 years old; 4, 50–59 years old; 5, 60–69 years old; and 6, ≥70 years old.

The relation between BMI and number of CNCDs

The average changes in BMI and number of CNCDs with age are shown in Fig. 1. It can be seen that the relation between BMI and number of CNCDs varies by gender and age group. In the 18–39 years age group, the number of CNCDs in both males and females increased with an increase in BMI and age. In the 40–59 years age group, the BMI of females remained relatively stable with increasing age; however, the average number of CNCDs increased with age. For males, BMI decreased with increasing age, and the number of CNCDs remained stable. In the ≥60 years age group, BMI decreased with increasing age in both males and females. It is also interesting to note that at the age of 50 years, the number of CNCDs in females caught up with the number of CNCDs seen in males.

Cut-off values of BMI for different gender and age groups

The seven CNCDs listed in the Methods section were regarded as indicators that reflected the overall status of CNCDs. Groups of individuals experiencing 2, 3, 4 or 5 different CNCDs simultaneously were analysed separately. The corresponding prevalence of each group is shown in Table 3. ROC analyses were used to analyse the cut-off values of BMI and the area under the curve (AUC) in each group under different conditions; results are shown in Table 3. When the number of simultaneous CNCDs was 2 and 3, the change in BMI cut-off values and AUC were too small to be a criterion for calculating BMI thresholds. In addition, when 5 CNCDs was taken as the outcome variable, the number of cases was zero. Therefore, experiencing 4 CNCDs simultaneously was the most appropriate condition for calculating the cut-off values of BMI. For males, the BMI cut-off values were ≥25 kg/m^2, ≥24 kg/m^2 and ≥23 kg/m^2 in the 18–39, 40–59 and 60–99 years age groups, respectively; the corresponding BMI cut-off points for females were ≥25 kg/m^2, ≥23 kg/m^2 and ≥25 kg/m^2.

Discussion

To our knowledge, this is the first study to investigate age- and gender-specific cut-off points of BMI in terms of the number of CNCDs among Chinese people. Our study showed the thresholds of BMI may be different by gender and age group. Nevertheless, it might be not suitable to determine cut-off values of BMI based on CNCDs for people aged ≥60 years. The findings of this study enable targeted prevention of overweight and obesity, and reduction of CNCDs by taking appropriate measures depending on gender and age.

This study showed that age was divided into three groups according to the distribution of BMI, and the relation between BMI and number of CNCDs varied by gender and age group. A study that used body fat rate as the evaluation index also showed that age and gender need to be taken into account when BMI is used to diagnose overweight and obesity.[19]

Table 2 – The comparison results in distribution of BMI between genders.

Age group (years)	Male		Female		t	P-Value
	n	BMI (kg/m^2) (mean ± SD)	n	BMI (kg/m^2) (mean ± SD)		
18–39	948	23.02 ± 3.55	948	22.11 ± 3.33	5.704	<0.001
40–59	1819	23.75 ± 3.25	1819	23.91 ± 3.31	1.520	0.129
60–99	1058	22.94 ± 3.49	1058	23.61 ± 3.82	4.197	<0.001
Total	3825	23.34 ± 3.42	3825	23.38 ± 3.54	0.499	0.618

BMI, body mass index; SD, standard deviation.

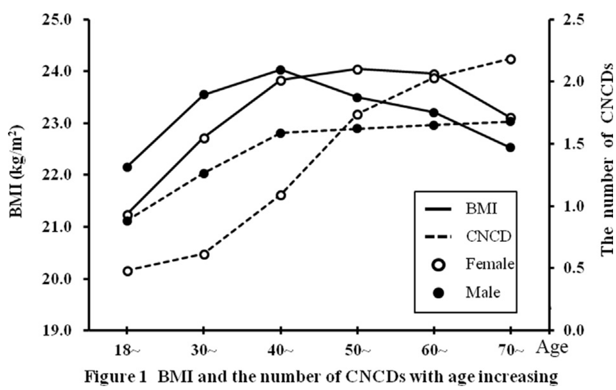

Fig. 1 – Body mass index (BMI) and the number of chronic non-communicable diseases (CNCDs) with increasing age. In the age group 18–39 years, the number of CNCDs in both men and women increased with the increase of BMI and age and the average prevalence of CNCDs in men was higher than that in women. In the 40–59 years age group, for women, the BMI remained relatively stable with age and the number of CNCDs increased with age, whereas for men, the BMI decreased with age and the number of CNCDs remained stable. At the age of about 50 years, the number of CNCDs in men and women reached the same level. In the ≥60-year-old age group, the BMI of men and women decreased with age and the number of CNCDs slowly increased with age in males, whereas the number of CNCDs increased faster in women, which resulted in the number of CNCDs in women being greater than in men.

ROC analyses were used to determine the threshold of BMI for predicting the number of CNCDs. Compared with the groups of individuals who experienced 2 or 3 CNCDs, if we regarded 4 CNCDs as the criterion for finding the cut-off points of BMI, the AUC was larger and the threshold of BMI was closest to the existing threshold for overweight (24 kg/m^2 [Chinese threshold] or 25 kg/m^2 [international threshold]). Therefore, this study used 'experiencing 4 CNCDs' as the criterion to determine the threshold of BMI. The reason why the cut-off values of BMI for predicting CNCDs varies among groups may be due to the change of sex hormones and distribution of adipose tissue in different genders with increasing age. Studies have demonstrated that compared to subcutaneous adipose tissue, visceral adipose tissue, especially abdominal fat, was correlated with metabolic diseases more closely, such as insulin resistance and dyslipidemia.[20,21] Studies have also reported that sex hormones can regulate body fat distribution;[22] androgen played a key role in adipose tissue accumulation in abdominal fat, while oestrogen can promote abdominal visceral adipose tissue to transfer to subcutaneous and peripheral regions.[22,23] We explored the cut-off points of waist circumference for predicting CNCDs; results showed that for males, the cut-off points decreased 1 cm between the 18–39 and the 40–59 years old age groups (85.5 cm vs 84.5 cm), and for females, the cut-off points increased 3 cm between the 18–39 and the 40–59 years old age groups (80.5 cm vs 83.5 cm), while the AUC in people aged ≥60 years were smaller than those aged <60 years old, which coincides with the change of adipose tissue distribution.

In men, androgen levels begin to increase from adolescence and reach peak values at 20–30 years of age when levels then start decreasing with increasing age, with a significant decrease above 60 years of age.[24] After 40 years of age, adipose tissue in

Table 3 – The prevalence of different CNCDs conditions and cut-off values of BMI.

Gender	Age group (years)	N	2 CNCDs			3 CNCDs			4 CNCDs			5 CNCDs		
			n[a] (%)	Cut-off BMI (kg/m^2)	AUC	n[a] (%)	Cut-off BMI (kg/m^2)	AUC	n[a] (%)	Cut-off BMI (kg/m^2)	AUC	n[a] (%)	Cut-off BMI (kg/m^2)	AUC
Male	18–39	988	340 (34.4)	≥22	0.711	147 (14.9)	≥23	0.732	49 (5.0)	≥25	0.779	10 (1.0)	≥26	0.827
	40–59	1846	930 (50.4)	≥24	0.690	482 (26.1)	≥24	0.718	170 (9.2)	≥24	0.725	34 (1.8)	≥26	0.763
	60–99	1106	533 (48.2)	≥23	0.689	302 (27.3)	≥23	0.691	119 (10.8)	≥23	0.682	31 (2.8)	≥23	0.724
Female	18–39	1113	187 (16.8)	≥23	0.672	56 (5.0)	≥23	0.688	7 (0.6)	≥25	0.888	0 (0.0)	–	–
	40–59	2161	990 (45.8)	≥23	0.632	471 (21.8)	≥23	0.639	143 (6.6)	≥23	0.683	29 (1.3)	≥26	0.803
	60–99	1232	784 (63.6)	≥22	0.652	485 (39.4)	≥22	0.659	218 (17.7)	≥25	0.674	50 (4.1)	≥22	0.683

AUC, area under the curve; BMI, body mass index; CNCD, chronic non-communicable disease.
[a] The number of individuals that experienced this number of CNCDs.

men might gradually transfer from the abdomen to the periphery. In other words, at the same BMI level, abdominal fat of middle-aged and elderly men was less than that of young men. That is, the negative health effects of high BMI in elderly men might be lower than those in young men. However, although the levels of androgen in middle-aged and elderly men were lower than those seen in young men, this study showed that the BMI cut-off value (≥24 kg/m^2) in the 40–59 years old age groups was lower than that (≥25 kg/m^2) of the 18–39 years old group, which may be because men aged 40-59 years play more social roles in their life than women do. In addition, men in the 40–59 years age group often experience high-pressure lifestyles and are exposed to more susceptibility factors of CNCDs, such as reduced immunity and occupational risks.[25,26] Thus, males in the 40–59 years age group should take control of BMI more strictly than they did at a younger age.

Oestrogen levels reach their peak when a woman is 30 years old, and subsequently gradually decrease until a sharp drop after menopause.[27] The cut-off value of BMI in the 40–59 years age group was 23 kg/m^2, compared to 25 kg/m^2 in the 18–39 years old group. This may be because the rapid decline in oestrogen, combined with a relative increase in androgen, may promote the redistribution of adipose tissue, making subcutaneous and peripheral adipose tissue transfer to the visceral region.[28] That is, at the same BMI level, adipose tissue is transferred to the abdominal region after menopause, which makes BMI more closely related to CNCDs.

In the 40–59 years age group, the cut-off value for BMI in females (≥23 kg/m^2) was lower than that of males (≥24 kg/m^2); thus, suggesting that for middle-aged people, females need to maintain a lower BMI than males to keep healthy. The reason for this may be that females could be more susceptible to central obesity when they enter menopause due to the decline of oestrogen levels, which might lead to a higher risk of CNCDs. Therefore, at the same BMI level, middle-aged females should pay more attention to the control of BMI than males.

An interesting phenomenon was found in this study: at the age of about 50 years, the average number of CNCDs in both males and females were the same (Fig. 1), which coincides with the changes in sex hormones in each gender. With the decline of androgen, abdominal adipose tissue in men would transfer to subcutaneous and peripheral regions. At the same time, with the decline of oestrogen, peripheral adipose tissue in women would transfer to the abdominal region.[22–24] At about 50 years of age, the distribution of both visceral adipose tissue and subcutaneous adipose tissue should be same in males and females. The results of this study proved this statement: there was no significant difference in the distribution of BMI between males and females in the 40–59 years age group.

From the perspective of AUC, before the age of 40 years, BMI had greater correlation with CNCDs and had higher efficiency in both males and females. However, this correlation weakened with increasing age, which was consistent with the study of Huang et al.[29] In addition, AUC was relatively small in both males and females aged ≥60 years, which may be a result of the gradual decline in activity intensity and reduced function of the organs and tissues. The effect of these factors on CNCDs was far greater than their effect on BMI; thus, it was not suitable to predict CNCDs with BMI in people aged ≥60 years. Winter et al.[2] also found that overweight in older people was not associated with the increase of all-cause mortality. A study by Flicker et al.[30] showed that in old people, the risk of death for overweight participants was 13% less than for normal-weight participants.

It should be noted that there are some limitations in this study. First, only seven CNCDs were considered, while some BMI-related diseases, such as tumours and chronic inflammation, were not considered. Also, the severity of disease was not taken into account on the determination of cut-off points. Second, this was a cross-sectional survey of longitudinal research; therefore, BMI and CNCDs were measured at the same time for individuals, so we could not determine the causal relationship between BMI and CNCDs (e.g. individuals may change their BMI after diagnosis of CNCDs). Third, this study did not take into account factors such as lifestyle, social pressure, mental health and other aspects that may impact the prevalence of CNCDs (e.g. at the same BMI, if the number of susceptible genes and the risk factors of environmental exposure are different, the severity and number of CNCDs might be different). Fourth, data analyses were not adjusted by sample weights for all records using the probability of selection at each stage of sampling; thus, the prevalence or mean value might not correctly represent the population as a whole.

Despite these limitations, our study contains several strengths. This study was based on the CHNS with a large sample size, wide coverage and good representation. The sequential sample cluster method was used to group age according to BMI. Compared with the system clustering, it did not disturb the original order of the age and the clustering result was more consistent with the true findings.[31] Moreover, when comparing BMI between genders, PSM was used to eliminate the influence of age composition.[18] In addition, unlike previous studies, we used the number of CNCDs instead of the all-cause mortality as an outcome variable for finding the cut-off points of BMI. As discussed, many factors leading to death are not correlated with BMI, and the CNCDs selected in this study have been confirmed to be closely related to BMI, so the results would be more accurate. Future research must take into account the effects of various factors, explore the reasonable threshold of BMI for predicting CNCDs, overweight and obesity in a larger area, so as to guide the prevention and control of CNCDs more accurately.

In conclusion, the cut-off threshold of BMI based on the number of CNCDs should be determined with consideration of age and gender. Monitoring BMI according to age and gender might reduce the occurrence of CNCDs. When a BMI is above the threshold, weight loss or other appropriate measures are recommended to reverse or slow progression of the disease.

Author statements

Acknowledgements

We thank the National Institute for Nutrition and Health, Chinese Center for Disease Control and Prevention and University of North Carolina at Chapel Hill for their contribution to this public data set.

Ethical approval

The protocol for the study was approved by the ethics committee of Chinese Center for Disease Control.

Funding

This work was supported by the National Natural Science Foundation of China [grant number: 81202277]; the Key Research Project for Colleges and Universities in Henan Province [grant number: 16A330003]; Cultivating grand for youth key teacher in Higher Education Institutions of Henan province [grant number: 2017GGJS012]; and the Natural Science Foundation of Henan Province [grant number: 182300410303].

Competing interests

None declared.

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