Relationship between BMI with percentage body fat and obesity in Singaporean adults – The Yishun Study.

Kexun Kenneth Chen
Geriatric Education and Research Institute Ltd
Shiou-Liang Wee (weeshiouliang@gmail.com)
Singapore Institute of Technology https://orcid.org/0000-0002-7853-4112
Benedict Pang
Geriatric Education and Research Institute Ltd
Lay Khoon Lau
Geriatric Education and Research Institute Ltd
Khalid Abdul Jabbar
Geriatric Education and Research Institute Ltd
Wei Ting Seah
Geriatric Education and Research Institute Ltd
Tze Pin Ng
Geriatric Education and Research Institute Ltd

Research article

Keywords: Obesity, Percentage body fat, BMI, Prevalence

Posted Date: December 16th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-53522/v2

Abstract

Background: The main aim of this study was to the determine relationship between BMI and BF% in Singaporean adults, derive a prediction model to estimate BF%, and to report population BF%. The secondary aim was to determine the prevalence of overweight and obesity based on BF% threshold and the new risk categories for obesity in Singaporean population.

Methods: This was a population-based study of 542 community-dwelling Singaporeans (21-90 years old, 43.1% men). Anthropometry and body composition were assessed. Relationship between BMI and BF% were analysed using multiple regression model. Prevalence of overweight and obesity were estimated using WHO and Singapore Ministry of Health (MOH) Clinical Practice Guidelines BMI classification, and BF% cut-off points of 25% and 35% for men and women respectively.

Results: We derived a prediction model to estimate BF% based on BMI, age, sex and ethnicity. The current cohort of Singaporeans have higher BF% at matching BMI, age and sex than Caucasians in the US and Europe, and a Singaporean cohort from 20 years ago. The overall population-adjusted prevalence of obesity according to WHO International classification (BMI ³30kg/m^2) was 12.9% (14.9% men; 11.0% women); and 26.6% (30.7% men; 22.8% women) according to MOH classification (BMI ³27.5kg/m^2). However, using BF% cut-off (>25% for men and >35% for women) resulted in very high prevalence of obesity of 82.0% (80.2% men; 83.8% women).

Conclusion: There is a large discrepancy between BF% and BMI measured obesity in Singaporean adults. The results confirmed that Singaporean adults have higher BF% at lower BMI compared to US and UK white counterparts; and that BF% in our population have increased over two decades.

1. Introduction

Obesity is a complex and chronic condition(1), clinically defined as the accumulation of excess body fat to the extent that it may have adverse effects on health(2). Obesity has long been associated with increased risks of mortality, cardiovascular diseases, diabetes, and cancer, and is associated with significant health and economic burden (3). Body mass index (BMI) has long been used to define obesity in adults. World Health Organization (WHO) recommends an international BMI cut-off point classification for adults: overweight is BMI 25-29·9kg/m^2 and obesity is BMI ³30kg/m^2(4). In 2016, WHO reported the global prevalence of obesity at 11% in men and 15% in women(5). Despite the relatively stable obesity prevalence in the US (30-34%) and UK (23-24%) between 2005 and 2015, the global prevalence has increased due to the rising trend in Asia (including China and India) which comprise a major portion of the world's population (6). Southeast Asia, with lower initial prevalence of obesity (2-15%), has also experienced increasing obesity over the last decade, in tandem with globalization, rapid urbanization, and increase in socio-economic status(7, 8).

Therefore, it is crucial to determine obesity or threshold of body fat that is associated with increased adverse health risk. Two commonly used methodology used to determine accumulation of body fat are waist circumference and BMI. Waist circumference (WC), measured at midpoint of the last palpable rib and top of iliac crest(9), has good correlation with abdominal adiposity, and strong association with cardiovascular mortality(10). WC have different cut-off points between Europeans (102cm for men and 88cm for women) and Asians (90cm for men and 80cm for women) due to different body sizes(9). BMI (body weight divided by height squared) is not a good indicator of body fat, as body weight comprises both fat and fat-free mass. Furthermore, the relationship between BMI, BF%, and body fat distribution differ with ethnicity(11, 12). Asians are found to have a higher body fat percentage for the same age, gender, and BMI, when compared to European white population, and have higher prevalence of type 2 diabetes (T2DM) and increased cardiovascular risk at lower BMI values compared to European white population(13). In a cross-sectional study of

Malaysian women aged 40-59, prevalence of obesity was 72.8 % based on BF% (BF% >33%) but only 20.6% when classified using BMI≥30kg/m^2(14). Therefore, having a common BMI cut-off for obesity is not appropriate, as these cut-off points were derived from studies of the relationship between BMI, morbidity and mortality in the Western populations(4, 15). In 2004, a WHO expert consultation was established to address the appropriate BMI for Asian populations(13). After a series of analyses of BMI, body composition and risk factors of six Asian population data set, consensus was to retain the international BMI cut-off points for Asian populations due to the diverse ethnicity and wide range of cut-off point observed within Asian populations, and further recommended adding cut-off points of 23, 27·5, 32·5 and 37·5kg/m^2 as points for public health actions(13). Under its current Ministry of Health (MOH) Clinical Practice Guidelines, Singapore adopted the cut-off point of 23kg/m^2 for overweight, and 27·5kg/m^2 for obesity(9), as Singaporeans have a higher prevalence of Type 2 diabetes and increased cardiovascular risk factors at BMI below 25kg/m2(16).

Therefore, a better measure of obesity should be based on an individual's percentage body fat (BF%). Various methods have been developed to measure BF%, including densitometry, dilution technique and dual energy X-ray absorptiometry (DXA). While WHO has a clear BMI cut-off for defining obesity, there is no clear consensus on the threshold for BF% for overweight and obesity. Previous studies have suggested that BF% greater than 25% for men and 35% for women is the threshold for diagnosing obesity, which were derived from corresponding BMI of 30kg/m^2 in Caucasians(17-19). In a population study, Vietnamese women were reported to have lower BMI, body weight and fat mass than US White women(20). However, the prevalence of BF% >35% were similar between the US White women (54%) and Vietnamese women (53%)(20).

Singapore is a multiracial and multicultural country, consisting of 74.4% Chinese, 13.4% Malays, 9.0% Indians, and 3.2% of various other races(21). In 2013, it was reported that among the three major ethnic group (i.e. Chinese, Malays, and Indians), Chinese had the lowest prevalence of obesity (BMI≥ 30kg/m^2) at 5.9%, Indians at 14.0%, and Malays at 20.7% (22). In a previous study, Singaporean Chinese was found to have higher cardiovascular risk at low levels of BMI(23). Relationship between BMI and BF% in Singaporeans was found to be different from Caucasians, and also among the three major ethnic groups(24). However, these studies were conducted about 20 years ago. In the recent WHO World Health Statistics, the Singapore population was reported to have similar mortality rate from cardiovascular diseases as Western populations(25). With the increase in mean BMI in Asians(8), the relationships between BMI and BF% among Singaporeans have likely changed. As Singapore had adopted the use of BMI 23kg/m^2 and 27.5kg/$m^2$for overweight and obesity, the prevalence of obesity based on BMI 23kg/m^2 and 27.5kg/m^2should also be studied. The primary aim of this study was to the determine relationship between BMI and BF% in the multi-ethnic (Chinese, Malay and Indian) population of Singapore, derive a prediction model to estimate BF%, and to report population BF%. The secondary aim was to determine the prevalence of overweight and obesity based on BF% threshold and the new risk categories for obesity in our population.

2. Methods

2·1 Settings

Participants were recruited among community-dwelling adults (≥21 years) from a large north-eastern residential town of Yishun in Singapore, with residential population of 220,320 (49·4% men), with 12·2% older adults (≥65 years)(21). This is similar to the overall Singapore residential population of 4·02 million (48·9% men), with 14·4% older adults (≥65 years)(21).

2·2 Participants

Random sampling methodology was employed to obtain a representative sample of approximately 300 male and 300 female participants, filling quotas of 20-40 participants in each sex- and age-group (10-year age-groups between 21-60 years; 5-year age-groups after 60 years). Conventionally, the sample size of 30 or greater per age-group is sufficient for normative measures(26). Between October 2017 and February 2019, using a two-stage random sampling method, 50% of all housing blocks were randomly selected, and a random 20% of the units in each block were approached for participant recruitment. Between March and November 2019, 50% of all housing blocks were randomly selected and all units were approached. Up to three eligible participants were recruited from each housing unit using a door-to-door recruitment method. Non-response units were re-contacted a second time at a different time of day on a later date. Older adults above 75 years old were additionally recruited through community sources and from a list of registered participants in four senior activity centres. Exclusion criteria were: individuals with disabilities, injuries, fractures or surgeries that affected function, neuromuscular, neurological and cognitive impairments, or more than five poorly controlled comorbidities. Pregnant women or those planning for pregnancy were also excluded. The estimated overall response rate was 39·0%. Ethics approval was obtained from the National Healthcare Group Domain Specific Review Board (2017/00212). All respondents gave informed consent before participation in the study.

2·3 Measurements and data collection

Body weight to the nearest 0·1kg and height to the nearest 0.1cm were measured using a digital balance and stadiometer (Seca, GmbH & Co. KG, Hamburg, Germany). Waist and hip circumferences were measured using a non-elastic, flexible measuring tape around the navel and widest part of the hips respectively. All participants underwent a DXA scan of the whole body (Hologic Discovery Wi, Hologic, Marlborough, MA, USA). The DXA scan was conducted by experienced radiographers. Body composition information - lean mass, fat mass, and bone mineral content, were obtained from the scan.

2·4 Overweight and Obesity

Classification of overweight and obesity by BMI were derived using WHO international criteria(4), and Singapore MOH Obesity Clinical Practice Guidelines(9, 13). Overweight and obesity were defined internationally as having a BMI 25·0-29·9kg/m^2, and BMI ³30·0kg/m^2, respectively. Singapore MOH Clinical Practice Guidelines defined overweight as BMI 23·0-27·4kg/m^2 and obesity as BMI ³27·5kg/m^2. The BF% cut-off points for obesity were set at 25% for men, and 35% for women(4, 17, 27). Waist circumference (WC) for abdominal obesity was defined as above 80cm for women, and above 90cm for men in Singapore(9).

2·5 Statistical analysis

All statistical analyses were performed using SPSS Statistics version 22·0 (IBM, Armonk, NY, USA). Relationship between BMI and BF% was analysed using multiple regression model. BF% was considered the dependent variable; 1/BMI, age, and ethnicity were independent variable. Data was analysed separately by sex. In exploratory analysis, the relationship between BMI and BF% was not linear, hence 1/BMI variable was used to linearise the data and to avoid the need for logarithmic conversion or the inclusion of power(28, 29). Potential interaction variables were explored in model development and a forward-backward stepwise procedure was utilised for the development of the prediction equation models. The dummy variables for ethnicity were E_1 and E_2. For Chinese $E_1 = 1$ and $E_2 = 0$, for Malays $E_1 = 0$ and $E_2 = 1$, and for Indians $E_1 = 0$ and $E_2 = 0$. Values are presented as mean ± standard deviation (SD), unless otherwise stated.

3. Results

3·1 Subjects

A total of 542 participants (43·1% men) aged 21 years and above were recruited for the study. Due to incomplete data from five participants, data from the remaining 537 participants (81·6% Chinese, 8·9% Malay, 6·7% Indians, and 2·8% from other races) were analysed. The ethnic distribution is similar to that of Singapore's population (21). For the BF% prediction equation model, only data from the three major ethnic groups are analysed. **Table 1** shows the demographic characteristics of the participants. As expected, men were taller and heavier, had lower BF%, higher fat-free mass, lower fat mass, and higher bone mineral content (p<0·005). BMI was not significantly different between men and women (p=0·071).

Table 1 Participant Demographic Characteristics

Variable	Men	Women	P value
Number of participants	229	308	
Age (yr)	58·9 ± 19·1	58·4 ± 18·5	0·736
Number of participants by age group			
21-29	25	30	
30-39	26	30	
40-49	22	40	
50-59	18	41	
60-64	29	27	
65-69	22	36	
70-74	28	27	
75-79	32	34	
80+	27	43	
Weight (kg)	70·2 ± 15·4	58·8 ± 10·9	<0·001
Height (cm)	166·6 ± 7·1	155·0 ± 6·4	<0·001
Waist Circumference (cm)	91·4 ± 15·4	81·6 ± 10·8	<0·001
Overall BMI (kg/m^2)	25·2 ± 4·9	24·5 ± 4·2	0·071
BMI by age-group			
21-29	27·1±8·2	22·5±4·5	
30-39	28·0±6·7	24·4±4·7	
40-49	27·2±3·8	25·7±4·3	
50-59	25·7±3·2	25·7±5·5	
60-64	24·0±2·9	24·4±3·6	
65-69	24·1±3·4	25·0±3·0	
70-74	24·2±3·2	22·9±3·7	
75-79	23·7±3·0	25·0±3·5	
80+	23·4±4·1	24·3±4·0	
Overall Body Fat Percentage(%)	30·0 ± 5·7	39·7 ± 5·2	<0·001
Body Fat Percentage by age-group			
21-29	29·6±8·1	37·0±6·4	
30-39	29·7±6·7	37·7±5·7	
40-49	31·0±4·8	39·2±4·7	
50-59	28·0±4·3	40·0±4·5	
60-64	29·1±5·1	40·9±4·9	
65-69	30·0±5·0	41·0±4·1	
70-74	30·9±5·8	39·3±5·0	
75-79	30·3±4·9	41·2±5·1	
80+	31·3±5·4	40·6±5·5	
Fat mass (kg)	21·0 ± 8·2	23·2 ± 6·6	<0·005
Fat mass Index (kg/m2)	7·6 ± 2·9	9·7 ± 2·7	<0·001
Fat-free mass (kg)	45·1 ± 8·9	32·6 ± 5·0	<0·001
Fat-free mass index (kg/m2)	16·2 ± 2·3	13·6 ± 1·8	<0·001
Bone mineral content (kg)	2·40 ± 0·43	1·88 ± 0·36	<0·001

Values are mean ± standard deviation, or actual number of participants

3·2 Relationship between BMI and BF%

The relationship between BMI and BF% was curvilinear (**Figure 1A**). We replaced BMI with 1/BMI as the independent variable to linearize the relationship (**Figure 1B & C**). The regression models with 1/BMI provided higher multiple *R* and *SEE* values, compared to logarithmic transformed BMI values, as was reported previously(30). **Table 2** shows the regression coefficients of the stepwise multiple regression. The final prediction equation derived was,

Table 2 Regression coefficient of the stepwise multiple regression of body fat percentage as dependent variable

	1/BMI		Age		E_1		E_2		Intercept		
	β	SE	*β*	SE	*β*	SE	*β*	SE	*β*	SE	*SEE*
Men											
	-545·136	43·194	-	-	-	-	-	-	52·181	1·802	4·06
	-614·186	40·939	0·090	0·014	-	-	-	-	49·692	1·693	3·72
	-601·503	41·768	0·094	0·014	-0·998	0·690	-	-	49·767	1·690	3·71
	-606·924	41·573	0·091	0·014	-1·993	0·846	-2·411	1·201	51·156	1·815	3·69
Women											
	-547·657	30·283	-	-	-	-	-	-	62·696	1·292	3·63
	-534·780	29·662	0·046	0·011	-	-	-	-	59·483	1·476	3·54
	-513·490	30·832	0·051	0·011	-1·285	0·550	-	-	59·342	1·467	3·51
	-514·639	30·326	0·051	0·011	-2·881	0·721	-3·094	0·924	60·993	1·542	3·45

1/BMI: 1 divided by Body Mass Index; Ethnicity - Chinese: $E_1 = 1$ and $E_2 = 0$; Malay: $E_1 = 0$ and $E_2 = 1$; Indian: $E_1 = 0$ and $E_2 = 0$; SE: Standard Error; SEE: Standard Error of Estimate

Men: Percentage Body Fat = 51·156 + 0·091 (Age) – 1·993 (E_1) – 2·411 (E_2) – 606·924 (1/BMI)

Women: Percentage Body Fat = 60·993 + 0·051 (Age) – 2·881 (E_1) – 3·094 (E_2) – 514·659 (1/BMI)

where multiple *R* = 0.73, SEE = 3.69% body fat for men (p<0.05), and multiple *R* = 0.75 and SEE = 3.45% body fat for women (p<0.05). Based on the estimated parameters of these equations, BF% values corresponding with BMI for men and women were derived (**Table 3**). Estimated BF% of White, Japanese, and Vietnamese were derived from studies that published ethnicity specific equation models(30, 31). Comparing estimated BF% from this study and from the 1998 National Heath Survey using equations published(24), men and women in 1998 were found to have lower BF% across all ages, ethnicity, and BMI categories, except for BMI 35·0kg/m^2 and above (**Supplementary Table)**.

Table 3 Estimated body fat percentage based on BMI of Singapore Chinese, Malay and Indian, compared with other ethnicities

	Men					Women				
	BMI of 18·5	BMI of 25	BMI of 30	BMI of 35	BMI of 40	BMI of 18·5	BMI of 25	BMI of 30	BMI of 35	BMI of 40
20-39y										
Chinese	19·1	27·6	31·7	34·6	36·8	31·8	39·1	42·5	44·9	46·8
Malay	18·7	27·2	31·3	34·2	36·4	31·6	38·8	42·3	44·8	46·5
Indian	21·1	29·6	33·7	36·6	38·7	34·7	42·0	45·4	47·8	49·7
White[29]	14·5	23·9	29·8	33·3	35·9	26·9	37·0	41·8	45·2	47·7
Japanese[29]	12·8	23·2	28·1	31·6	34·3	24·6	35·2	40·2	43·8	46·5
Vietnamese[30]	18·3	26·5	29·8	30·6	28·8	29·2	37·4	40·7	41·5	39·7
40-59y										
Chinese	20·9	29·4	33·5	36·4	38·5	32·8	40·1	43·5	46·0	47·8
Malay	20·5	29·0	33·1	36·0	38·1	32·6	39·9	43·3	45·8	47·6
Indian	22·9	31·4	35·5	38·4	40·5	35·7	43·0	46·3	48·8	50·6
White[29]	15·6	25·4	30·0	33·3	35·8	27·5	37·4	42·2	45·6	48·1
Japanese[29]	13·4	23·8	28·7	32·2	34·9	25	35·5	40·2	44·1	46·8
Vietnamese[30]	19·1	27·2	30·5	31·5	29·7	30·1	38·5	41·8	42·4	40·6
60-79y										
Chinese	22·7	31·3	35·3	38·2	40·4	33·9	41·1	44·6	47·0	48·8
Malay	22·3	30·8	34·9	37·8	39·9	33·6	40·9	44·4	46·8	48·6
Indian	24·7	33·3	37·3	40·2	42·4	36·7	44·0	47·4	49·9	51·7
White[29]	19·0	28·0	32·3	35·3	37·6	31·0	39·9	44·1	47·1	49·4
Japanese[29]	13·9	24·3	29·3	32·8	35·4	25·3	35·8	40·9	44·4	47·1
Vietnamese[30]	20·1	28·2	31·6	32·4	30·6	31·0	39·1	42·5	43·3	41·5

Estimated body fat percentage calculated centering on the ages of 30, 50, and 70 years.

3·3 Prevalence of overweight and obesity

The prevalence of overweight and obesity are presented in **Table 4**. According to WHO International BMI classification, the overall population-adjusted prevalence of overweight was 34·4% (39·1% men; 29·9% women), and obesity was 12·9% (14·9% men; 11·0% women). Using the MOH classification, the prevalence of overweight was 41·8% (44·5% men; 39·3% women) and obesity 26·6% (30·7% men; 22·8% women). Using WHO proposed BF% cut-off, prevalence of obesity increased to 82·0% overall (80·2% men; 83·8% women). Using WC criteria, prevalence of abdominal obesity was 59·1% (55·7% men; 62·3% women).

Table 4 Sample and population-age adjusted prevalence of overweight and obesity based on BMI, BF and WC

	Sample Estimates					Population-Adjusted Estimates				
	Overall	21-59yrs	≥60yrs	≥65yrs	≥75yrs	Overall	21-59yrs	≥60yrs	≥65yrs	≥75yrs
Total										
Overweight	33·9	32·3	34·9	32·7	30·1	34·4	33·4	37·0	33·4	30·0
Obese	9·5	15·9	4·6	4·8	6·6	12·9	16·2	3·7	3·7	6·5
BF%	83·2	81·0	84·4	85·3	83·8	82·0	80·9	85·2	87·5	84·0
WC	63·9	55·2	70·0	70·9	70·6	59·1	55·6	68·8	69·9	70·2
OW_{MOH}	42·8	39·2	45·3	44·2	45·6	41·8	40·8	46·0	44·2	45·4
OB_{MOH}	21·8	29·3	16·0	15·5	14·0	26·6	30·3	16·3	15·4	14·0
Men										
Overweight	37·6	39·6	36·2	32·1	29·3	39·1	39·3	38·6	31·8	28·5
Obese	9·6	19·8	2·9	3·7	3·4	14·9	19·4	2·0	3·0	3·4
BF%	81·2	79·1	82·6	85·3	81·0	80·2	79·1	83·2	88·9	80·2
WC	54·1	54·9	53·6	54·1	50·0	55·7	56·7	52·9	53·6	49·1
OW_{MOH}	45·4	41·8	47·8	45·0	43·1	44·5	42·6	50·0	45·5	41·8
OB_{MOH}	21·8	37·4	11·6	11·0	8·6	30·7	37·4	11·6	10·4	8·7
Women										
Overweight	31·2	27·7	34·1	33·6	31·2	29·9	27·8	35·5	34·9	31·2
Obese	9·4	13·5	6·0	5·7	9·1	11·0	13·1	5·2	4·2	8·9
BF%	84·7	82·3	86·8	86·4	87·0	83·8	82·6	87·1	86·2	86·9
WC	71·1	55·3	84·4	85·0	87·0	62·3	54·6	83·4	84·3	86·9
OW_{MOH}	40·9	40·9	37·6	43·7	44·3	39·3	38·2	42·3	43·0	48·2
OB_{MOH}	21·8	24·1	19·8	19·3	18·2	22·8	23·6	20·6	19·8	18·1

Overweight (BMI 25·0-29·9kg/m^2) and obesity (BMI ≥30·0kg/m^2) classification based on WHO international classification.; BF% (body fat percentage) - Men: 25%; Women: 30%; WC (waist circumference) - Men: 90cm; Women: 80cm; OW_{MOH} (BMI 23·0-27·4kg/m2) and OB_{MOH} (BMI ≥27·5kg/m^2) classification uses the Singapore MOH Clinical Practice Guidelines BMI classification.

4. Discussion

4·1 Percentage Body Fat

In this study, we established the relationship between BMI and BF% in Singapore Chinese, Malay and Indian adults. We compared the estimated BF% with other ethnicity, and also with an earlier study on Singapore population from 20 years ago. Comparing among ethnicities, Singapore Chinese, Malays, and Indians are found to have higher BF% compared to Caucasian. This supports the findings from the Singapore study in 2000 (24) and other reports that some Asians population have greater fat mass than Caucasians(14, 32-34). However, there are other contrasting findings from other Asian populations, such as Vietnamese(31) and Polynesian(35) population that for similar sex, age, and BMI, the BF% was lower compared to Caucasians – showing the ethnic diversity in percentage body fat in Asia.

Our finding updates the 2000 report (24) in that current cohort of Singaporeans have higher BF% at matching BMI, age and sex compared to the cohort from 20 years ago, except within the high BMI range(35-40kg/m^2) and Malay men at BMI 18·5kg/m^2(24). In our study, Indians have the highest BF%, followed by the Chinese, then Malays. The 2000 study reported that Indians had the highest BF%, but with Chinese having the lowest BF%(24). The difference in BF% among different ethnic groups in the same population was previously reported(34). The changes among Singaporeans may be

due to changes in energy balance. Average daily energy intake increased 10·3% from 2004 to 2010 with majority (59·4%) of the population exceeding the daily recommended energy intake(36). This increase in energy intake was not offset by the subsequent 5% reduction in average daily energy intake between 2010 to 2018(37). The Chinese (578kcal) had the highest increase in energy intake (Malay: 533kcal; Indians; 429kcal)(36), which could explain Chinese overtaking the Malays in BF% ranking.

4·2 Prevalence of overweight and obesity

The population-adjusted prevalence of overweight and obesity of Singaporeans, classified using WHO international BMI categories, are 34·4% (men: 39·1%; women: 29·9%) and 12.9% (men: 14.9%; women: 11.0%) respectively (Table 4). However, using the Singapore Health Ministry BMI cut-off, the population-adjusted prevalence of overweight increase to 41·8% (men: 44.5%; women 39.3%), and obesity 26·6% (men: 30·7%; women: 22·8%) (Table 4). When adopting BF% criteria (>25% in men and >35% in women), population-adjusted obesity prevalence was substantially higher at 82.0% (men: 80·2%; women: 83·8%) (Table 4). The corresponding high population -adjusted prevalence of WC>80cm for women and >90 cm for men (59.1% overall, 55.7% for men and 62.3% for women in Table 4) suggests that central obesity account for much of this excess body fat in our population. Such substantial higher prevalence with BF% criteria had also been reported in the Vietnamese(31). It is well-known that BMI, though highly specific, has low to moderate sensitivity when defining obesity and underestimate prevalence of adult excess body fat, particularly in Asians(31, 38). While the Chinese and Koreans have proposed population-specific BF% cut-off(33, 39), there is yet no Asian consensus in BF% cut-off point. Our finding is a step towards such a consensus.

A previous study reported that the lowest all-cause mortality rate in Singapore Chinese was at BMI 18·5-19·9kg/m^2, with mortality rate significantly increased at BMI ³26·0kg/m^2 for non-smokers(16), which is lower than the WHO Asian recommendation(13). Using our derived equation, BF% at BMI 18·5-19·9kg/m^2 equates to 20·9-23·2% in Chinese men and 32·8-34·8% in Chinese women aged 50 years. At BMI 26kg/m^2, BF% equates to 30·4% in Chinese men and 40·9% in Chinese women, which is about 5% higher than the WHO BF% cut-off. Using the criteria of BF% ³30·4% in men and ³40·9% in women, 45% of men and 44% of women have increased mortality risk. These estimates are much higher than the prevalence based on BMI ³30kg/m^2, but much lower than using the WHO BF% cutoff. Differences in prevalence based on BMI is expected because the relationship between BMI and body fat content varies according to body build and proportion(2). People with low relative sitting height will have a relatively low BMI compared to their BF%(40), but our Asian population have high relative sitting height(41). The smaller body frame of Singapore Chinese partially contributed to their having higher BF% at the same BMI(41). Physical inactivity is likely another contributing factor. The 2010 National Health Survey found 39·1% of Singaporeans did not meet the recommended physical activity guidelines(42). The increase in energy intake and lack of physical activity could explain the high BF% in Singaporeans. Such high BF% in Singaporeans may explain the leading contribution of cardiovascular disease and cancer to disease burden(43). Our study suggests that WHO international and local Health Ministry BMI classification still underestimated the obesity prevalence in Singapore(24). Given the high discrepancy between prevalence of obesity using BMI versus BF%, the prediction equations for BF% from BMI provides a basis and impetus towards establishing healthy body fat ranges in Singapore.

4·3 Strength and limitation

The strengths of this study are its population-based, random selection of participants and hence representativeness and validity of data. The ideal method to determine body composition is the multi-compartment model(30), however such method is inaccessible, expensive and require participants to undergo multiple test. DXA, though may have its limitations, has been used in multiple national population surveys and considered the “gold standard” for measuring body composition parameters(31, 44). There are some limitations to this study. Though due to random sampling, the

ethnic distribution of the study population was similar to that of Singapore's, the sample size of Malays and Indians were not adequately powered to make statistical comparisons between ethnic groups. Hence, our findings on ethnic differences in obesity need to be confirmed with a larger sample of Malay and Indian ethnic groups. A thorough investigation into the nutrition intake and physical activity may help understand the large discrepancy between BMI and BF%. The ideal approach to define threshold for obesity is based on the relationship between BF%, all-cause and cause-specific mortality in a long-term prospective study.

In conclusion, our study found a large discrepancy between BF% and BMI measurement in Singaporean adults. The results confirmed that Singaporean adults have higher BF% at lower BMI compared to Caucasians and that BF% in our population have also increased over two decades. Further investigation into the body build, nutrition intake, physical activity level among the different ethnic groups may help understand the relationship between BF% and BMI.

Abbreviations

BMI Body mass index

BF% Percentage body fat

DXA Dual energy x-ray absorptiometry

MOH Ministry of Health

T2DM Type 2 Diabetes

US United States of America

UK United Kingdom

WC Waist Circumference

Declarations

Ethics approval and consent to participate: Ethics approval was obtained from the National Healthcare Group Domain Specific Review Board (2017/00212). All respondents signed informed consent before their participation in the study.

Consent for publication: Not applicable

Availability of data and material: The data that support the findings of this study are available from the corresponding author SLW, upon reasonable request. The data are not publicly available due to institutional regulations regarding data containing information that could compromise the privacy of research participants.

Conflicts of interest/Competing interests: Kexun Kenneth Chen, Benedict Wei Jun Pang, Lay Khoon Lau, Khalid Abdul Jabbar, Wei Ting Seah, Tze Pin Ng, and Shiou-Liang Wee declare that they have no conflict of interest.

Funding: This research was supported as part of a core funding from the Ministry of Health (MOH) of Singapore to GERI (intramural project GERI 1609).

Authors' contribution:

- Drafting of the manuscript: KKC, SLW, TPN
- Study concept and design: SLW, TPN

- Acquisition of data: BWJP, LKL, KAJ, KKC, WTS
- Analysis and interpretation of data: KKC, BWJP, SLW, LKL, KAJ, WTS, TPN
- Critical revision of the manuscript for important intellectual content: SLW, TPN

All authors have read and approved the manuscript.

Acknowledgement: The authors gratefully acknowledge the support of Daniella Ng, Queenie Tan, Dr. Lilian Chye, Sylvia Ngu, Aizuriah Mohamed Ali, Mary Ng, Xing Ying Chua and Shermaine Thein in study logistics and data collection for this study. The authors gratefully acknowledge the strong support of Prof Pang Weng Sun in making this Yishun study possible.

References

1. Kyle TK, Dhurandhar EJ, Allison DB. Regarding Obesity as a Disease: Evolving Policies and Their Implications. Endocrinol Metab Clin North Am. 2016;45(3):511-20.
2. World Health Organization. Obesity: preventing and managing the global epidemic: report of a WHO consultation Geneva: World Health Organisation; 2000.
3. Wang YC, McPherson K, Marsh T, Gortmaker SL, Brown M. Health and economic burden of the projected obesity trends in the USA and the UK. The Lancet. 2011;378(9793):815-25.
4. World Health Organization. Physical status: the use and interpretation of anthropometry. 1995.
5. World Health Organization. Global Health Observatory (GHO) data – Overweight and obesity 2020 [Available from: https://www.who.int/gho/ncd/risk_factors/overweight_obesity/obesity_adults/en/.
6. Chooi YC, Ding C, Magkos F. The epidemiology of obesity. Metabolism: Clinical and Experimental. 2019;92:6-10.
7. Ramachandran A, Chamukuttan S, Shetty SA, Arun N, Susairaj P. Obesity in Asia–is it different from rest of the world. Diabetes Metab Res Rev. 2012;28 Suppl 2:47-51.
8. NCD Risk Factor Collaboration (NCD-RisC). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults. The Lancet. 2017;390(10113):2627-42.
9. Health Promotion Board, Ministry of Health. Obesity HPB-MOH Clinical Practice Guidelines 1/2016. Singapore: Health Promotion Board, Singapore; 2016.
10. Ross R, Neeland IJ, Yamashita S, Shai I, Seidell J, Magni P, et al. Waist circumference as a vital sign in clinical practice: a Consensus Statement from the IAS and ICCR Working Group on Visceral Obesity. Nat Rev Endocrinol. 2020;16(3):177-89.
11. Wang J, Thornton JC, Russell M, Burastero S, Heymsfield S, Pierson Jr RD. Asians have lower body mass index (BMI) but higher percent body fat than do whites: comparisons of anthropometric measurements. American Society for Clinical Nutrition. 1994;60:23-8.
12. Deurenberg-Yap M, Chew SK, Lin VFP, Tan BY, Van Staveren WA, Deurenberg P. Relationships between indices of obesity and its comorbidities in multi-ethnic Singapore. International Journal of Obesity. 2001;25(10):1554-62.
13. World Health Organization. Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. Lancet. 2004;363(9403):157-63.
14. Johari SM, Nordin NJ, Sahar MA, Sulaiman AH, Shahar S, Teng NIMF, et al. High body fat percentage among adult women in Malaysia: the role of lifestyle. Journal of Fundamental and Applied Sciences. 2017;9(4S):905-19.
15. Deurenberg P. Universal cut-off BMI points for obesity are not appropriate. Br J Nutr. 2001;85(2):135-6.

16. Odegaard AO, Pereira MA, Koh WP, Gross MD, Duval S, Yu MC, et al. BMI, all-cause and cause-specific mortality in Chinese Singaporean men and women: the Singapore Chinese health study. PLoS One. 2010;5(11):e14000.
17. De Lorenzo A, Deurenberg P, Pietrantuono M, Di Daniele N, Cervelli V, Andreoli A. How fat is obese? Acta Diabetologica. 2003;40(SUPPL. 1):254-7.
18. Deurenberg P, Weststrate JA, Seidell JC. Body mass index as a measure of body fatness: age- and sex-specific prediction formulas. British Journal of Nutrition. 1991;65(2):105-14.
19. Deurenberg P, Yap M, van Staveren WA. Body mass index and percent body fat: a meta analysis among different ethnic group. International Journal of Obesity. 1998;22:1164-71.
20. Ho-Pham LT, Lai TQ, Nguyen ND, Barrett-Connor E, Nguyen TV. Similarity in percent body fat between white and Vietnamese women: implication for a universal definition of obesity. Obesity (Silver Spring). 2010;18(6):1242-6.
21. Department of Statistics S. Population Trends, 2019. 2019.
22. Lee YS, Biddle S, Chan MF, Cheng A, Cheong M, Chong YS, et al. Health Promotion Board-Ministry of Health Clinical Practice Guidelines: Obesity. Singapore Med J. 2016;57(6):292-300.
23. Deurenberg-Yap M, Tan BY, Chew SK, Deurenberg P, van Staveren WA. Manifestation of cardiovascular risk factors at low levels of body mass index and waist-to-hip ratio in Singaporean Chinese. Asia Pacific Journal of Clinical Nutrition. 1999;8(3):177-83.
24. Deurenberg-Yap M, Schmidt G, Van Staveren WA, Deurenberg P. The paradox of low body mass index and high body fat percentage among Chinese, Malays and Indians in Singapore. International Journal of Obesity. 2000;24(8):1011-7.
25. World Health Organization. World Health Statistics 2020: Monitoring health for the SDGs, sustainable developement goals. Geneva: World Health Organization; 2020 2020.
26. Hogg R, Tanis E, Zimmerman D. Probability and statistical inference. 9th ed: Pearson; 2015.
27. Arroyo M, Rocandio AM, Ansotegui L, Herrera H, Salces I, Rebato E. Comparison of Predicted Body Fat Percentage From Anthropometric Methods and From Impedance in University Students. Br J Nutr. 2004;92(5):827-32.
28. Flegal KM. Is an inverted weight-height index a better index of body fatness? Obesity Research. 1992;5:93S.
29. Heymsfield SB, Tighe A, Wang ZM. Nutritional assessment by anthropometric and biochemical methods. In: Shils ME, Olson JA, Shike M, editors. Modern nutrition in health and disease. 8th ed. Philadelphia: Lea and Febiger; 1992. p. 812-41.
30. Gallagher D, Heymsfield SB, Heo M, Jebb SA, Murgatroyd PR, Sakamoto Y. Healthy percentage body fat ranges: An approach for developing guidelines based on body mass index. American Journal of Clinical Nutrition. 2000;72(3):694-701.
31. Ho-Pham LT, Lai TQ, Nguyen MT, Nguyen TV. Relationship between Body Mass Index and Percent Body Fat in Vietnamese: Implications for the Diagnosis of Obesity. PLoS One. 2015;10(5):e0127198.
32. Lu YC, Lin YC, Yen AM, Chan WP. Dual-energy X-ray absorptiometry-assessed adipose tissues in metabolically unhealthy normal weight Asians. Sci Rep. 2019;9(1):17698.
33. Li L, Wang C, Bao Y, Peng L, Gu H, Jia W. Optimal body fat percentage cut-offs for obesity in Chinese adults. Clin Exp Pharmacol Physiol. 2012;39(4):393-8.
34. Gurrici S, Hartriyanti Y, Hautvast JG, Deurenberg P. Relationship between body fat and body mass index: differences between Indonesians and Dutch Caucasians. European Journal of Clinical Nutrition. 1998;52(11):779-83.
35. Craig P, Halavatau V, Comino E, Caterson I. Differences in body composition between Tongans and Australians: time to rethink the healthy weight ranges? International Journal of Obesity. 2001;25:1806-14.

36. Health Promotion Board Singapore. Report of the National Nutrition Survey 2010. Singapore: Health Promotion Board Singapore; 2010.
37. Health Promotion Board Singapore. National Nutrition Survey 2018 Shows Gradual Improvements in Singaporeans' Dietary Habits: Health Promotion Board Singapore; 2018 [Available from: https://www.hpb.gov.sg/article/national-nutrition-survey-2018-shows-gradual-improvements-in-singaporeans-dietary-habits.
38. Okorodudu DO, Jumean MF, Montori VM, Romero-Corral A, Somers VK, Erwin PJ, et al. Diagnostic Performance of Body Mass Index to Identify Obesity as Defined by Body Adiposity: A Systematic Review and Meta-Analysis. Int J Obes (Lond). 2010;34(5):791-9.
39. Kim CH, Park HS, Park M, Kim H, Kim C. Optimal cutoffs of percentage body fat for predicting obesity-related cardiovascular disease risk factors in Korean adults. American Journal of Clinical Nutrition. 2011;94(1):34-9.
40. Norgan NG. Population differences in body composition in relation to body mass index. European Journal of Clinical Nutrition. 1994;48:S10-25.
41. Deurenberg P, Deurenberg-Yap M, Wang J, Lin FP, Schmidt G. The impact of body build on the relationship between body mass index and percent body fat. International Journal of Obesity. 1999;23:537-42.
42. Epidemiology & Disease Control Division MoH, Singapore. National Health Survey 2010. Singapore: Epidemiology & Disease Control Division, Ministry of Health; 2010.
43. Epidemiology & Disease Control Division MOH, Singapore , Institute For Health Metrics And Evaluation. The Burden of Disease in Singapore, 1990–2017: An overview of the Global Burden of Disease Study 2017 results. WA: IHME; 2019.
44. Kelly TL, Wilson KE, Heymsfield SB. Dual energy X-ray absorptiometry body composition reference values from NHANES. PLoS ONE. 2009;4(9):e7038-e.

Figures

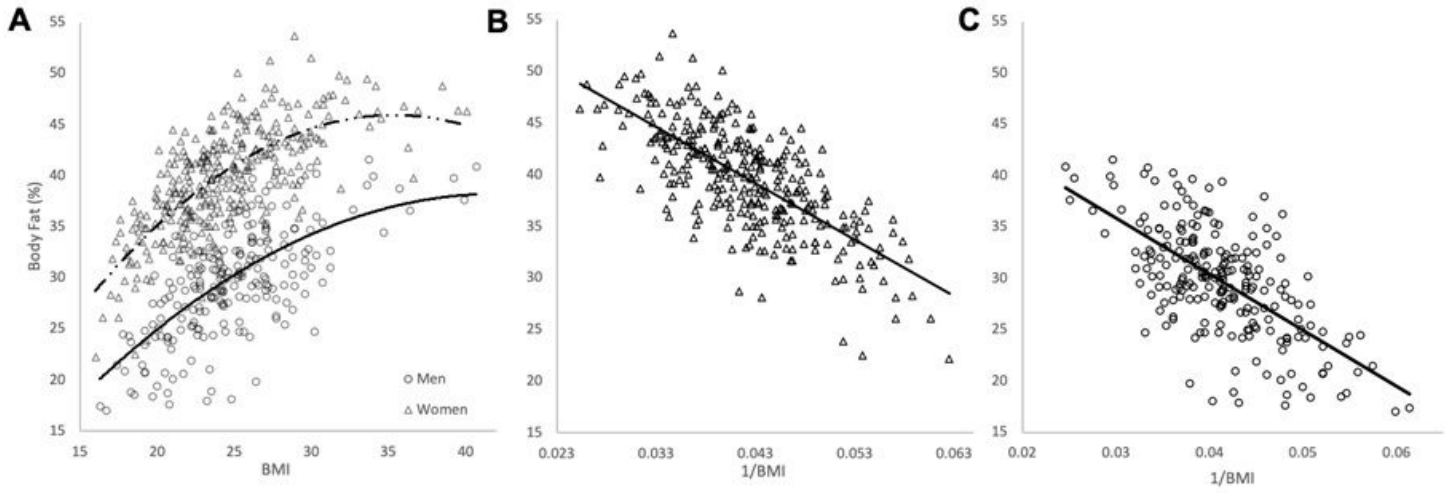

Figure 1

(A) Curvilinear relationship between BF% versus BMI (B) Linearize relationship between BF% and 1/BMI in women; y = -547.66 (x) + 62.696; R2 = 0.52 (C) Linearize relationship between BF% and 1/BMI in men; y = -545.14 (x) + 52.181; R2 = 0.42

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryTable.pdf