Comparison of the effectiveness of body mass index and body fat percentage in defining body composition

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INTRODUCTION Body mass index (BMI) has limited diagnostic performance due to its inability to discriminate between fat and lean mass. This study was conducted to compare the effectiveness of body fat percentage (BFP) against BMI in defining body composition.

METHODS A cross-sectional study was conducted on students aged 17–30 years in Melaka, Malaysia. Basic anthropometric measurements were acquired using a manual weighing scale, measuring tape and a fixed stadiometer. BFP was calculated using the United States Navy formula. Data was tabulated and analysed using Epi Info and Statistical Package for the Social Sciences software. Pearson's correlation coefficient and Kappa values were used. A p-value < 0.05 was considered statistically significant.

RESULTS Out of the 490 subjects recruited, 43% of males and 24.6% of females were found to be overweight, while 14.3% of males and 7.8% of females were obese, when calculated using BMI. However, 8.9% of males and 22.8% of females were considered obese based on the BFP.

CONCLUSION BFP plays a more important role in distinguishing between healthy and obese individuals, as it has a greater ability to differentiate between lean mass and fat mass compared to BMI.

Keywords: body fat percentage, body mass index, obese, overweight
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INTRODUCTION

In recent years, obesity has become an increasingly important medical concern,(1) as the number of overweight and obese individuals is increasing at an alarming rate worldwide.(2) The rapid and marked socioeconomic advancement in Malaysia in the past two decades has brought about significant changes in the lifestyles of communities, including the dietary patterns of Malaysians.(3)

Based on the World Health Organization (WHO) guidelines of body mass index (BMI) ≥ 25.0 kg/m^2 to define overweight and BMI ≥ 30.0 kg/m^2 to define obesity, it was reported that 15.1% of Malaysian adult males were overweight and 2.9% were obese, while 17.9% of adult females were overweight and 5.7% were obese.(4) BMI, which was first described by Quetelet in the mid-19th century, based on the observation that body weight is proportional to the square of the height in adults with normal body frames,(5) has been used as a tool to diagnose obesity for the past 30 years. However, this formula does not take waist size, which is a clearer indicator of obesity, into consideration.(6) In developing his index, Quetelet had no interest in obesity. His concern was defining the characteristics of the 'normal man' and fitting the distribution around the norm.(7,8)

This simple index of body weight has been consistently used in numerous epidemiological studies, and has been widely recommended for individual use in clinical practice to guide recommendations for weight control and weight loss.(9-11) Although BMI-defined obesity has been associated with mortality, various studies worldwide have shown that overweight individuals have similar or even better outcomes for survival and cardiovascular events when compared to those classified as having 'normal' body weight.(12) Taking these facts into consideration, a better indicator is required to define obesity. Body fat percentage (BFP) is a measure of how much of the body's composition is fat.(13) BMI, on the other hand, has limited diagnostic performance due to its inability to discriminate between fat and lean mass.(14) This study aimed to show that BFP defines body composition better than BMI.

METHODS

This was a cross-sectional study conducted on healthy, multi-ethnic male and female students (aged 17–30 years) from Melaka Manipal Medical College (MMMC) and Multimedia University (MMU). The participants were selected based on universal sampling. A total of 555 students were selected, out of which 267 were from MMMC and 288 from MMU. Only students with a BMI ≥ 18.5 kg/m^2 were included in the study (n = 490). Written consent was obtained from all the participants, and approval was obtained from both institutions prior to the study. All participants were questioned verbally for adverse medical and surgical conditions, including pregnancy and lactation for females, for which they were excluded. Participants were allowed to decline participation in the study. Details of measurements that would be carried out had been announced in the students' respective classes a week prior to

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the dates fixed to carry out the procedure. They were asked to empty their bladder before the measurements were done.

All personnel carrying out the anthropometric measurements were previously trained and followed standard techniques as adapted from the United States (US) Navy[15] and National Health and Nutrition Examination Survey (NHANES).[16] Both the BMI and BFP were measured. Body weight was measured with a manual load scale calibrated to the nearest 0.5 kg. Students were requested to be dressed in simple clothing and no footwear. They were told to stand at the centre of the weighing machine to prevent measurement error. Their stature was measured to the closest 0.5 cm using a fixed stadiometer. They were positioned with their head, buttocks and heels against the upright surface of the stadiometer with the head in the Frankfort horizontal plane.[12]

BMI was calculated using the formula: weight (kg)/height^2 (m^2). For the BFP, a few circumference measurements were required, namely the neck, waist and hip. For both males and females, the neck circumference was measured just inferior to the larynx, with the tape sloping slightly downward to the front.[15] For males, measurement for the abdomen was taken at the level just above the iliac crest at a horizontal plane. The personnel taking the measurements ensured that the measuring tape was snug but not pressed into the skin.[15-18] For females, the abdomen circumference was taken at the level of minimal abdominal width.[16] The hip circumference was taken at the largest horizontal circumference of the hips;[16] the abdominal circumference was taken at the end of normal expiration.[14] This method was chosen over other available methods such as dual-energy X-ray absorptiometry (DEXA), bioelectrical impedance, skin callipers or hydrostatic body fat testing, as it is inexpensive, fast, convenient and requires minimal skills in addition to producing results that are comparable to those of hydrostatic body fat testing, which is the gold standard.

BFP was calculated using the US Navy formula,[15] whose validity is acceptable and comparable to the gold standard.[15] Moreover, the measuring techniques used have been standardised, thus reducing measurement errors and making the calculated BFP reliable (results were rounded to the nearest 0.1). The formula is as follows:

For males:

$$\frac{495}{1.0324 - 0.19077(\log[\text{abdomen} - \text{neck}]) + 0.15456(\log[\text{height}])} - 450$$

For females:

$$\frac{495}{1.29579 - 0.35004(\log[\text{abdomen} + \text{hip} - \text{neck}]) + 0.22100(\log[\text{height}])} - 450$$

This study was done as part of a health awareness programme, and all participants were provided free health education regarding diet and exercise at the end of data collection. A questionnaire was also given to each student requesting for their demographic profile (name, age, role number and ethnicity), knowledge and practice in relation to diet and exercise, BMI and BFP.

Table I. Frequency and percentage of BMI and BFP statuses of the participants.

Parameter	No. (%)		
	Male (n = 258)	Female (n = 232)	Total (n = 490)
BFP			
Obese	23 (8.9)	53 (22.8)	77 (15.7)
Not obese	235 (91.1)	179 (77.2)	413 (84.3)
BMI			
Normal	110 (42.6)	157 (67.7)	267 (54.5)
Overweight	111 (43.0)	57 (24.6)	168 (34.3)
Obese	37 (14.3)	18 (7.8)	55 (11.2)

BFP: body fat percentage; BMI: body mass index

Data was presented based on gender and correlation between BMI and BFP. The standards of BMI used were based on the BMI standards in Singapore, which were revised in 2005.[19] As the ethnic diversity of Singapore is similar to Malaysia, it would be considered an appropriate reference. According to the revised standards, the BMI cut-offs for overweight and obese are 23–27.4 kg/m^2 and ≥ 27.5 kg/m^2, respectively.[19] For the BFP, the standards followed were based on the American Council on Exercise (ACE), which classifies BFP-defined obesity as ≥ 25% and ≥ 32% in males and females, respectively.[20] BFP is a ratio and hence, the classification developed by the ACE is accepted by the Centre of Disease Control and the American College of Sports Medicine as the benchmark for BFP.[20] Data was tabulated in Microsoft Excel. Pearson's correlation coefficients were constructed between BMI and BFP to assess the degree of association between these two variables. Kappa values were also used to demonstrate the agreement between BMI and BFP. Data analysis was done using EPI Info (US Centre for Disease Control and Prevention, Atlanta, GA, USA) and the Statistical Package for the Social Sciences version 16.0 (SPSS Inc, Chicago, IL, USA). A p-value < 0.05 was considered to be statistically significant.

RESULTS

From the data obtained, the mean age of the subjects was 21.5 ± 1.9 years for males and 21.6 ± 2.0 years for females (data not shown). 52.7% (n = 258) of the participants were males and 47.3% (n = 232) were females. Out of the 490 subjects, 40.8% (n = 200) were Chinese, 29.2% (n = 143) were Malay, 23.9% (n = 117) were Indian and 6.1% (n = 30) belonged to other ethnic or racial groups. The mean BMI was 24.3 ± 3.9 kg/m^2 for males and 22.5 ± 3.2 kg/m^2 for females, while the mean BFP was 16.8% ± 6.1% for males and 27.9% ± 6.1% for females. Using BMI (≥ 27.5 kg/m^2) as the cut-off for obesity, 14.3% of males and 7.8% of females were categorised as obese. However, using the ACE definition as the cut-off for obesity (≥ 25% for males and ≥ 32% for females), 8.9% of males and 22.8% of females were categorised as obese. Table I shows the frequency and percentage of BMI and BFP statuses of the subjects.

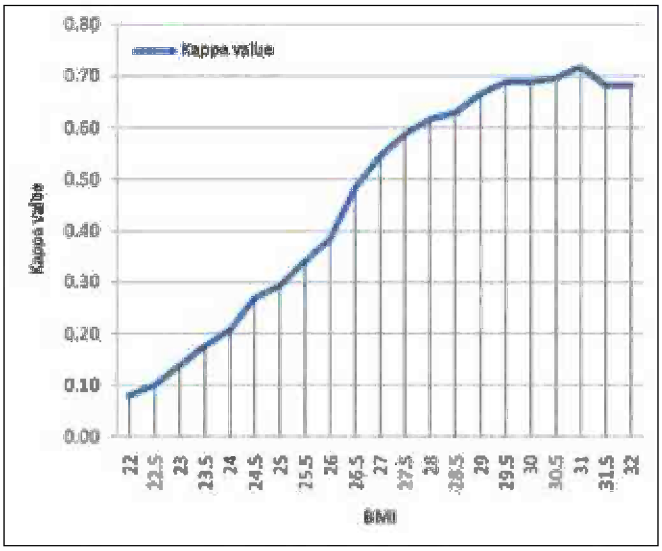

Fig. 1 Graph shows the kappa values of BMI ranging from 22 kg/m^2 to 32 kg/m^2 in males compared with BFP, as measured by the US Navy formula.

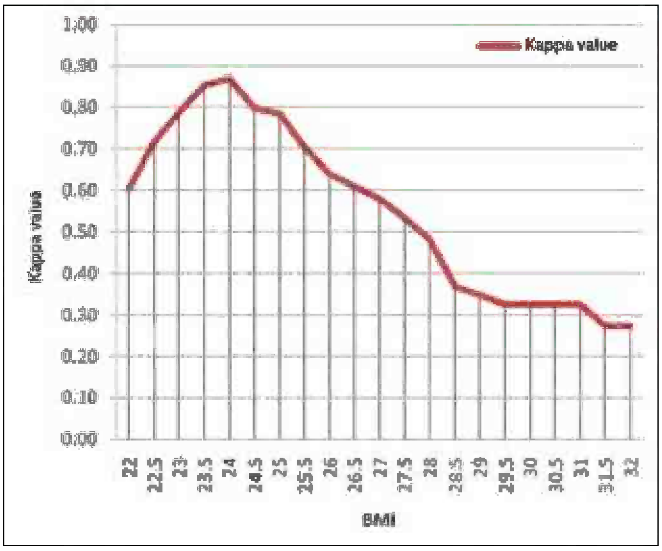

Fig. 2 Graph shows the kappa values of BMI from 22 kg/m^2 to 32 kg/m^2 in females compared with BFP, as measured by the US Navy formula.

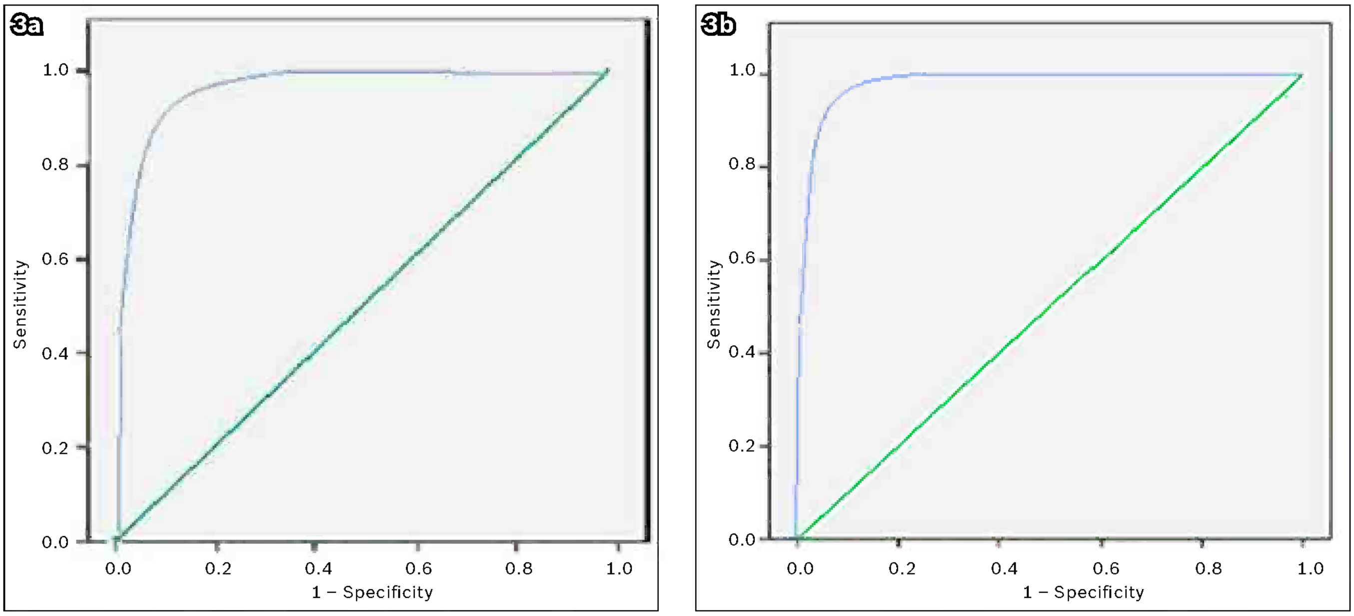

Fig. 3 Graphs show the ROC curves in (a) males and (b) females.

It was observed that among the three main ethnic groups, the proportion of obese individuals according to BFP was highest among the Indians at 22.2% (26/117), followed by the Malays at 14.7% (21/143) and the Chinese at 12% (24/100). It was also observed that based on BMI, the proportion of obese individuals was also highest among the Indians at 15.4% (18/117), followed by the Malays at 11.9% (17/143) and the Chinese at 8% (16/200).

According to the BMI standards in Singapore, which were revised in 2005, overweight and obesity are BMI ≥ 23.0 kg/m^2 and ≥ 27.5 kg/m^2, respectively. A BMI cut-off of ≥ 27.5 kg/m^2 had overall poor sensitivity (48.7%) and good specificity (95.7%) to detect BFP-defined obesity. After stratifying by gender, it was found that BMI ≥ 27.5 kg/m^2 had good sensitivity in males (82.6%), but only 34% sensitivity in females. On the other hand, the specificity was good for both genders, being 92.6% and 100.0% for males and females, respectively. However, a BMI cut-off of ≥ 23 kg/m^2 had overall good sensitivity of 100% and poor specificity of 64.7%. After differentiating by gender, it had good sensitivity (100%) for both males and females; however, there was good specificity in females (87.7%) but not in males (47.2%). Figs. 1 and 2 show the kappa values of BMI ranging from 22 kg/m^2 to 32 kg/m^2 for both genders. At the BMI cut-off of ≥ 23 kg/m^2, the corresponding kappa values showed poor agreement for males (0.14) and good agreement for females (0.79). At the BMI cut-off of ≥ 27.5 kg/m^2, the corresponding kappa values showed fair agreement for both males and females (0.59 and 0.53, respectively).

The receiver operating characteristic (ROC) curves showed an overall area under the curve of 0.98 for BMI to detect BFP-defined obesity (≥ 25 kg/m^2 in males and ≥ 32 kg/m^2 in females). On the basis of gender, the area under the curve was lower in males (0.968, Fig. 3a) compared to females (0.987, Fig. 3b). The overall correlation between BMI and BFP showed a variability of 20% ($R^2 = 0.20$, $p < 0.00001$). After stratifying by gender, BFP described 67% of the variability in BMI in males ($R^2 = 0.67$, $p < 0.00001$) and 82% in females ($R^2 = 0.82$, $p < 0.00001$). The overall correlation between BMI and lean mass showed a variability of 30% ($R^2 = 0.30$, $p < 0.00001$). After stratifying by gender, lean mass explained 56% of the variability in BMI in males ($R^2 = 0.56$, $p < 0.00001$) and 31% in females ($R^2 = 0.31$, $p < 0.00001$). Thus, BMI correlates better with BFP in females compared to males. On the other hand, BMI correlates better with lean mass in males compared to females.

DISCUSSION

We observed that BMI has a varied diagnostic capability according to gender. The limitation of BMI as an effective screening tool was highlighted when a large proportion of men and women were falsely classified as overweight or obese based on BMI, when in reality, these individuals had healthy levels of body fat. At a BMI cut-off of 27.5 kg/m^2, the overall sensitivity of BMI was low, missing over half the individuals who were truly obese. On the other hand, at this cut-off point, it had good specificity, with a relatively good positive predictive value. The correlation between BMI and BFP is good when each gender is considered separately. It is also observed that lean mass and BMI correlate better with males compared to females.

A BMI cut-off of 23 kg/m^2 seemed to be the better of the two benchmarks when all 490 participants were compared. At a sensitivity of 100% and specificity of 64.7%, it was observed that a total of 148 (57.3%) male and 75 (32.4%) female students were categorised as either overweight or obese. On the other hand, when BFP was used as the diagnostic parameter, considering males and females separately due to the different cut-off points, only 23 (8.9%) male and 53 (22.8%) female students were actually obese. This shows that BMI has miscategorised a large number of healthy individuals, particularly males, due to its inability to differentiate between lean mass and adipose tissue. A similar limitation of BMI has been highlighted in numerous other studies.[14] BMI assumes that one's fatness is independent of age, gender and ethnicity.[21] Body mass comprises lean mass (bone tissue, muscle tissue, connective tissue and organs – essentially everything in the body excluding body fat) and fat mass. Hence, the numerator of BMI comprises both lean mass and fat mass. Both of these masses have opposite effects on health. Those with a higher lean mass essentially have a higher basal metabolic rate and better physical fitness,[14] and are less prone to obesity-related diseases. On the other hand, those with higher fat mass face the deleterious effects of excessive adipose tissue.[14] For example, if two individuals of the same gender with a BMI of 26 kg/m^2 were compared, one with a higher proportion of lean mass and the other with a higher proportion of fat mass, they would have different risks to the deleterious effects of adipose tissue. This re-emphasises that BMI is unable to differentiate between lean mass and fat mass. WHO defines overweight and obesity as abnormal or excessive fat accumulation that may impair health.[22] Using this definition, BFP would be a more appropriate health parameter to define obesity, as it enables differentiation of lean mass and fat mass.

If the diagnostic performance of BMI is studied closely, it would be observed that the ability of BMI to identify actual obese individuals is good at higher percentiles of BMI. However, a finding that may contradict the current BMI cut-off for obesity (27.5 kg/m^2) is that for females, although it has very good specificity, the sensitivity is very poor. Thus, BMI would be able to identify those who are not obese with absolute certainty, but would miss out a big group of people who are actually obese. Hence, BMI would be a poor screening tool for females with regard to BMI-defined obesity. However, when the cut-off point for BMI is lowered to 23.0 kg/m^2, the diagnostic performance improves drastically, and this explains the higher mortality rate in females as compared to males in some studies with BMI-defined overweight.[23] On the other hand, when the same cut-off of 27.5 kg/m^2 is used for males, BMI is both sensitive and specific. Although it may identify some healthy individuals, especially those who are physically active, it would be less likely to miss those who are actually obese. Hence, there is a disparity between the diagnostic performances of BMI for the two genders. It is obvious that the limitation of BMI seems to be more focused in the intermediate ranges between 23 kg/m^2 and 27.5 kg/m^2. We also observed that BMI overestimated males and underestimated females who were actually obese. However, another study carried out by NHANES found that BMI underestimates the number of individuals who are actually obese.[14] This may be due to the large number of subjects in their study.

Our results also showed that there is a difference in agreement between BMI and BFP using kappa values when males and females are compared; the agreement is best at BMI 23.5 ± 0.85 kg/m^2 ($p < 0.05$) for females and 31.0 ± 0.72 kg/m^2 ($p < 0.05$) for males. Similarly, the ROC curve also shows that the area under the curve was higher in females compared to males for BMI to detect BFP-defined obesity. This was also observed in the NHANES study.[14] The majority of overweight males and some obese males are healthy due to their higher proportion of lean mass. This means that lean mass weight mainly makes up the numerator of BMI. Studies have shown that muscle tissue is heavier than adipose tissue, weighing 1.06 g/ml and 0.9 g/ml, respectively.[24,25] Hence, muscle tissue is 18% more dense than adipose tissue. Thus, the body of an individual who has a high proportion of muscle mass tends to be heavier than that of the average sedentary individual. This explains the agreement between BMI and BFP for males at 31 kg/m^2. Males in this study were probably moderate to well-built on the average. On the other hand, this agreement is achieved at a much lower cut-off value in females, since females have a higher proportion of body fat. This fact has also been pointed out in other studies.[26] For example, when a 23-year-old male and female with a similar BMI of 24.1 kg/m^2 were compared, it was observed that the male had a BFP of 18.1% whereas the female had a BFP of 35%. The hormonal make-up of females causes them to store more fat as compared to males. Moreover, their biological and physiological needs also supersede those of males.[26] Fat in women is mostly found in areas of the breasts, hips and upper thighs.[27]

The prevalence of obesity also differs according to the different ethnic groups. From the three main ethnic groups in our study, it was observed that the proportions of both BFP-defined and BMI-defined obesity were highest among the Indians (22.2% and 15.8%, respectively), followed by Malays (14.7% and 11.9%, respectively) and Chinese (12% and 8%, respectively). Similar findings were observed in two different studies carried out in Singapore.[28,29] However, a national study carried out in Malaysia and another study in Singapore found the highest prevalence of obesity among the Malays.[30,31] This is probably due to the difference in dietary intake and level of physical activity among the three groups. Among Asians and Caucasians, however, it has been observed that for the same BMI, Asians have a higher proportion of body fat[28] owing to the difference in genetic make-up, dietary patterns and environmental factors, which likely explains the revision in BMI cut-off values for Asians.

There are other documented methods to determine body composition, namely DEXA, densitometry, skinfold measurements and bioelectrical impedance analysis. Each method has its own pros and cons. DEXA is a device that involves the combination of a whole body scanner with X-ray beam of both high- and low-energy peaks.[32] This device is used to differentiate between bone mineral mass, fat mass and fat-free mass through differential absorption of the X-rays by various tissues.[32,33] The radiation dose is 1/10th of a basic chest X-ray.[32] This method is easier than hydrostatic weighing, and has good accuracy and reproducibility; however, due to its cost, exposure to X-rays, the need for a trained operator and usage of appropriate software, it is still not widely used.[32] Hydrostatic weighing or densitometry has been the 'gold standard' for several decades.[32] The accuracy of densitometry is close to that of DEXA, with a 3%–4% chance of error; however, due to the cost, time and facilities required for attaining the parameters, it is not an ideal tool for large-scale studies.[32]

Bioelectrical impedance analysis, also known as resistance measurements, works on the theory that lean mass contains ions in water solution, which are able to conduct electricity better than fat mass.[32] Individuals with a higher resistance have a higher fat mass or lower lean mass.[32] Body shape affects the calculation and hence, is taken into consideration. This harmless electrical current is passed through the body via a two- or four-electrode device in either a standing or recumbent position.[32,33] The method is simple, quick and painless. However, the cost of the device may vary, and the device requires controlled conditions to attain accurate and reliable measurements, as body water content, body temperature and time of the day may affect the results.[34] Skinfold thickness measurement is a good method for direct measurement of body fat; however, it requires measurements from multiple sites, usage of special callipers (e.g. Harpenden)[35] and a trained person for taking the measurements. Moreover, the presence of interobserver variation also affects the results.[32] This is a simple technique that is relatively cheaper than the other techniques mentioned. Although it is not a valid predictor of BFP, as intra-abdominal and intramuscular fat is not measured, it is still an effective monitoring tool to keep track of alterations in body composition over time.[32]

Due to feasibility constraints, we could not select our participants by any probability sampling method. All individuals were encouraged to voluntarily participate. As the results from this study were comparable to the national estimates done in Singapore with a similar ethnic diversity,[29] we presume that the feasibility constraints of this study had minimal impact on the outcome.

In conclusion, we have found that although BMI is fairly accurate in the higher ranges, compared to BFP, it is an inefficient screening tool to detect above normal levels of body fat, especially among those who have been classified as overweight or mildly obese. Thus, using methods to directly or indirectly estimate the body fat of an individual not only ensures a proper diagnosis, but also prevents the implications of miscategorising patients. Since BMI has long been incorporated into the medical system, we recommend that separate BMI cut-offs be used for males and females, especially when defining those above normal, as both have different BFPs for the same BMI. Therefore, we propose that BFP should be considered by clinicians before diagnosing a patient as overweight or obese solely based on BMI.

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