\ASSESSMENT OF A PROPOSED BMI FORMULA IN PREDICTING BODY FAT PERCENTAGE AMONG FILIPINO YOUNG ADULTS

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ABSTRACT

The body mass index (BMI), while routinely used in evaluating adiposity, cannot distinguish betweenfat and lean body mass, and isinfluencedby various factors likeage, sex, ethnicity,and activity level.Consequently, BMI canpotentiallymisclassify weight status among the athletic, physically active, tall- and short-statured, whoselean-to-fat ratios vary considerably from average individuals. In this cross-sectional study, we assessed the performance of a modified BMI formula ($1.3[kg]/m^{2.5}$, proposed by Oxford professor Lloyd Trefethen) against the traditionalQuetelet formula (kg/m^2) in predicting body fat percentage (%BF)measured using bioelectric impedance analysis (BIA), and in diagnosing overweight/obesity among a sample of Filipino young adults.A total of 190 participants (74 males, 116 females) were included in the analysis, on which 1000 bootstrap replications were subsequently performed. Agreement between the two BMIs is significantly higher among males (κ=0.9306 vs κ=0.7139).For both sexes, the traditional BMI quadratic full model demonstrated the highest adjusted R^2 values (males: 0.6733; females: 0.8262), and the lowest AIC and BIC values.Similarly, the traditional BMI had consistently higher measures of diagnostic accuracyand AuROCs (males: 0.9221 vs 0.9147; females: 0.9517 vs 0.9430), albeit nonsignificant. In conclusion, both BMI_Q and BMI_M are comparable, but with BMI_Qperformingnon-significantly better than BMI_M in predicting %BF and in discriminating between normal and overweight-obese weight classifications.

Keywords:*body mass index, Trefethen, body fat percentage, Filipino, young adults*

INTRODUCTION

Obesity, described as abnormal or excessive fat accumulation, has been steadily growingin prevalence since the 1970s and has more than tripled over a forty-year period.[1,2] Relative to many high-income countries, the increase in obesity rates appears to be faster in Asia.[3]As of 2014, about5.1% of the Filipino populationwas classified as obese, representing a 24% relative increase in the number of obese Filipino adults from 2010.[4]In this same 2014 report, the estimated proportion of overweight Filipino adults was 23.6%.While these figures are relatively low compared to the neighboring countries, theystill translate to roughly 18 million obese and overweight individuals. This increasing trend in obesity is concerning because it imposes an additional burden on top of already-existing problems of undernutrition and infectious diseases typical inlow- and middle-income countries.[5]In 2016, Philippine healthcare spending on obesity alonehas already amounted to somewhere between US$ 500 million and US$ 1 billion.[6]

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Currently, body mass index (BMI) is an accepted anthropometric measure used in screening for overweight and obesity, and for categorizing individuals into different weight groups (underweight, normal, overweight, and obese). This is invariably due to its noninvasiveness and satisfactory correlation with body fat percentage (%BF).[7]BMI is, however, limited in that it cannot distinguish between fat and lean body mass,[8] and is influenced by factors independent of height and weight, like age, sex, ethnicity, muscle mass, and activity level. As a result, its use can potentially misclassify the weight status ofathletic, physically active, tall- and short-statured individuals, whose lean-to-fat ratios can vary considerably from average individuals.ThisBMI–body fat discordance carries a consequence of introducing important bias when estimating the effects related to obesity,[9] as well as the possibility of failing to identify individuals at risk for chronic diseases.[10,11]

Although there are other validated anthropometric measuresfor estimating adiposity,[12,13]BMI use remains routine due to its convenience and ease in measurement,in that even self-reported weight and height can be used to calculate it for weight classification purposes.[14]The BMI formula itself was developed more than 150 years ago by Belgian mathematician Adolphe Quetelet during a period when body fat estimation necessitated using more convenient methods that did not involve sophisticated calculations. However, Lloyd Trefethen, an applied mathematician and professor of numerical analysis at the University of Oxford, critiques this formula, stating that it divides the weight by too much with shorter people, and by too little with tall people,[15]consequentlyunderestimating adiposity in theformer and overestimatingit in thelatter. In light of this, he proposed a modified BMI formula he believed would approximate actual body sizes and shapes better.[16]In this study, we aimed to assess the performance of the modified BMI formulaagainst the traditional Queteletformula in predicting %BF and in screening for overweight/obesity among a sample of Filipino young adults. As a secondary objective, we aimed to assessand compare the diagnostic accuracies of both BMI measures in identifying the overweight-obese state.

METHODS

Study Design

This is a cross-sectional study that was carried out during the second semester of academic year 2018–2019 at the De La Salle Medical and Health Sciences Institute (DLSMHSI), City of Dasmariñas, Cavite Province, Philippines. Ethics approval of the study was granted by the Institutional Ethics Review Committee of the College of Medicine of DLSMHSI.

Study Population

The study population comprised of medical students enrolled at the DLSMHSI. This population was chosen because it is composed of young Filipino adults originating from various areas in the Philippines (though predominantly from the Central Luzon and CALABARZON regions) who came to enroll in the institute’s medicine program. While the predominant age range is early-to-mid-twenties, a sizable proportion of younger students coming from accelerated pre-med programs (e.g., Human Biology, Medical Biology, Biochemistry) enroll every academic year. There are also older students who decided to enroll after engaging in the workforce for a number of years, thus making this a heterogenous population age-wise. Furthermore, given the presumed high level of stress associated with medical school and the relatively sedentary lifestyle of medical students, it was anticipated that the prevalence of overweight and obesity in this population will be comparable with that indicated in the nationwide statistics.[4]

All first- to third-year students duly enrolled in the medicine program of DLSMHSI were considered for possible participation in the study. Fourth-year students were not included because of their limited accessibility due to their full-time hospital duties. For the academic year 2018–2019, there were 262first-years, 280second-years, and 241third-years, bringing the study population size to 783.

Participant Recruitment

In order to reach the students, the research team made classroom visits during which a brief overview and explanation of the study objectives and procedures were presented. Participation in the study was on a voluntary basis, and a participant was deemed eligible if they werebetween 18 and 35 years of age at the time of recruitment, and of Asian or Southeast Asian descent.The presence of any of the following at the time of recruitmentwarranted exclusion: chronic illness (diabetes mellitus; hypertension; heart failure; malignancy), acute myocardial infarction or stroke within the past 6 months, pregnancy (for females), chronic corticosteroid use, conditions affecting posture (kyphosis, scoliosis, or kyphoscoliosis), oractive engagement in any body-building or exercise program. All eligible participants were provided with written consent forms thereafter. Those who did not give consent for participation were excluded from the studyaccordingly.

Data Collection

Data collection was performed by direct interview and direct measurement. To facilitate this, the entire group of eligible participantswas broken down into batches. The batches werethen instructed to proceed to the College of Medicine skills laboratory at scheduled times for anthropometric measurements, so that data collection would not interfere with their classes.Booths in the skills laboratory were utilized to ensure privacy of the participants during measurements.All participants were instructed not to eat or drink anything at least two hours prior to their scheduled measurement times to avoid obtaining spurious readings with bioelectric impedance analysis (BIA).Prior to anthropometrics measurement, participants were asked for fill out a questionnaire inquiring about their demographic data, smoking history (quantified as pack-years) and alcohol intake (quantified as average number of drinks per week). All digital equipment were calibrated prior to use and regularly throughout the entire process of data collection. All measurements were taken twice by two members of the research team.

For heightmeasurement, a verified height rule was mounted on a hard flat wall surface with its base at floor level. To check its proper vertical placement, a carpenter’s level was used. Participants were asked to remove their shoes and any heavy outer clothing. Hairstyles were adjusted or undone, and hair accessories removed to allow for proper placement of the stadiometer head piece. Participants were then instructed to stand (with back to the height rule) as straight as possible with arms hanging loosely at their sides and feet flat on the floor. The stadiometer head piece was then placed in position, and the height recorded to the nearest 0.1 centimeter.

Weight and %BF were measured using a digital weighing scale and body composition monitor (Tanita BC-543 One Size). The instrument was placed on a flat hard-floor (non-carpeted) surface verified using a carpenter’s level. As with height measurement, participants were instructed to remove their shoes and any heavy outer clothing, as well asempty their pockets and remove any jewelry, watches, and other accessories they were wearing. Since BIA was used to quantify %BF, participants were asked to stand barefoot on the footplates of the weighing scale. Weight was recorded to the nearest 0.1 kilogram, while %BF was recorded to the nearest 0.1 percent.

Table 1. Body fat percentage (%BF) ranges according to BMI weight classification.

Weight classification	%BF	
	Males	Females
Underweight	<13	<25
Normal	13–23	25–35
Overweight	23.1–28	35.1–40
Obese	>28	>40

Waist circumference (WC) was measured using a standard tape measure, the length of which was verified regularly using a calibrated length rod. Stretched-out tape measures were replaced accordingly. The participants were asked to remove their upper garments except for lightclothing that can be lifted up to the epigastric level. The midpoint between the subcostal margin of the last palpable rib and the upper margin of the iliac crest was used as anatomic landmark on which the tape measure is firmly held and maintained in horizontal position. All measurements were recorded to the nearest 0.1 centimeter.

The measured heights and weights were then used to calculate BMI using both the traditional Quetelet formula (BMI_Q =weight in *kg*/[height in *m*]^2) and the proposed modified formula (BMI_M = 1.3[weight in *kg*]/[height in *m*]$^{2.5}$).Separate weight classifications according to Asian-Pacific cutoff points[17] (underweight: <18.5; normal: 18.5–22.9; overweight: 23.0–24.9; obese: ≥25.0) were determined for each participant using the two computed BMI values. Table 1 shows the reference values for %BF used in this study.

A case report form was created for each participant, where all demographic information (age, sex, smoking history, alcohol intake) and raw measurements (weight, height, %BF, WC) were recorded and verified concomitantly.The data were then encoded according to the instructions specified in the coding manual, and inputted toMicrosoft© Excel in a data layout format appropriate for importing to the statistical software.

Statistical Analysis

Summary statistics (mean and standard deviation for normal data, mean and range for non-normal data, and frequency and percentages for categorical data) were computed for all variables. All continuous variables were tested for normality using the Shapiro-Wilk test.Differences in the variables between the sexes were assessed using either two-mean or two-proportion *t*-test.

The correlations between BMI_Q and BMI_M, and between the BMI values and %BF were quantified using Pearson's correlation. Agreement between weight classifications based on BMI_Q and BMI_M were determined using Cohen's κ coefficient.To assess the utility of BMI_Q and BMI_M on predicting %BF, sex-specific regressionmodels for each BMI type were constructed using robust polynomial regression analysis in anticipation of multivariate normality assumption violations;only the linear and quadratic relationships were examined since a cubic relationship between BMI and %BF is not supported by literature.Due to the small population size, the invitation to participate was extended to all members of this population. In anticipation of a low participation rate, the bootstrap resampling method (performing 1000 replications) was utilized in the analysis. For all regression models, age, WC, smoking history and alcohol intake were used as covariates.Likelihood ratio tests were performed to assess goodness of fit between nested regression models. To estimate the relative quality of the models for BMI_M and how it performs against the models for BMI_Q, the Akaike information criteria (AIC) and Bayesian information criteria (BIC) were quantified and compared. For issues of missing data, chained multiple imputation by predictive mean matching was performed.

Table 2. Demographic and Anthropometric Characteristics of Participants

Characteristic	Males (n = 74)	Females (n = 116)	*p*-value
Age, median (range)	22 (19–30) years	22 (19–27) years	0.614
Height, mean (SD)	168.9 (5.0) cm	156.1 (5.7) cm	<0.001
Weight, mean (SD)	76.1 (14.8) kg	53.2 (11.5) kg	<0.001
WC, median (range)	88.5 (66.5–125.0) cm	73 (59.5–102) cm	<0.001
%BF, mean (SD)	23.2 (5.5) %	29.6 (5.2) %	<0.001
Smoking history, median (range)	0 (0–20) pack-years	0	0.029
Alcohol intake, median (range)	1 (0–10) drinks/week	0 (0–3) drinks/week	0.002
BMI_Q, mean (SD)	26.6 (5.0)	23.0 (4.3)	<0.001
<18.5 (n, %)	1 (1.3%)	13 (11.2%)	
18.5–22.9 (n, %)	19 (25.7%)	54 (46.6%)	
23.0–24.9 (n, %)	11 (14.9%)	19 (16.4%)	
≥25.0 (n, %)	43 (58.1%)	30 (25.9%)	
BMI_M, mean (SD)	26.7 (5.0)	23.9 (4.5)	<0.001
<18.5 (n, %)	1 (1.3%)	4 (3.4%)	
18.5–22.9 (n, %)	20 (27.0%)	56 (48.3%)	
23.0–24.9 (n, %)	12 (16.2%)	20 (17.2%)	
≥25.0 (n, %)	41 (55.4%)	36 (31.0%)	

WC: waist circumference
%BF: body fat percentage
BMI_Q: BMI computedusing the traditional Quetelet formula
BMI_M: BMI computedusing the modified BMI formula proposed by Lloyd Trefethen

Since reference values for %BF differ between males and females, measures of diagnostic accuracy– sensitivity, specificity, positive predictive values (PPV), negative predictive values (NPV), and likelihood ratios (LR+ and LR–) –were determined for each sex stratum. Sex-specific receiver operating characteristic (ROC) curves were likewise plotted to identify the optimumBMI_Q and BMI_M cut-off values that distinguish between the normal and overweight–obeseweight classifications. The respective areas under the curve (AuROCs) were also calculated accordingly.

All statistical analyses were carried out using Stata 14.2 (StataCorp, College Station, TX). Results wereconsidered statistically significant if *p*-value <0.05. Ninety-five percent confidence intervals (95% CI) were also calculated for all estimates.

RESULTS

Of the 783students in the study population that were invited, only 190 (24.3%; 74 males and 116 females) participated in the study. The median age of the sample was 22 years (range: 19–30 years).Table 2 summarizes their demographic and anthropometric data. Only 3 students (1.6%, all males) were smokers at the time of data collection. Regarding alcohol intake,29 (15.3%) admitted having had at least 1 drink per week (19 males vs 10 females; p = 0.0014). In our sample, males had significantly higher values for height, weight, WC, BMI$_Q$ and BMI$_M$ (all p

Table 3. Correlation matrix of anthropometric measures, stratified by sex
(95% confidence intervals in parentheses)

	Males			Females		
	BMI$_Q$	BMI$_M$	%BF	BMI$_Q$	BMI$_M$	%BF
BMI$_Q$	1.000			1.000		
BMI$_M$	0.997 (0.995,0.998)	1.000		0.995 (0.993,0.997)	1.000	
%BF	0.785 (0.677,0.860)	0.782 (0.672,0.858)	1.000	0.833 (0.769,0.883)	0.815 (0.745,0.870)	1.000

Table 4. Contingency tables featuring degrees of agreement between weight classifications based on the traditional Quetelet and proposed modified BMI formulas, stratified by sex.

Males					
BMI$_Q$	BMI$_M$				
	Underweight	Normal	Overweight	Obese	Total
Underweight	1	0	0	0	1
Normal	0	19	0	0	19
Overweight	0	1	10	0	11
Obese	0	0	2	41	43
Total	1	20	12	41	74
Agreement: 96.0% (95% CI 91.5%, 100.0%) Expected agreement: 41.6%; p<0.001 Cohen's κ: 0.9306 (95% CI 0.7658, 1.0000)					

Females					
BMI$_Q$	BMI$_M$				
	Underweight	Normal	Overweight	Obese	Total
Underweight	4	9	0	0	13
Normal	0	47	7	0	54
Overweight	0	0	13	6	19
Obese	0	0	0	30	30
Total	4	56	20	36	116
Agreement: 81.0% (95% CI 73.9%, 88.2%) Expected agreement: 33.7%; p<0.001 Cohen's κ: 0.7139 (95% CI 0.5969, 0.8309)					

<0.001), while females had significantly higher %BF ($p<0.001$). Among males, 40 (54.05%) had %BF ≥23.1%, while among females, 19 (16.38%) had %BF ≥35.1%.

Table 3 shows the correlation matrix that includes both BMI types and %BF, stratified according to sex. High correlation exists between BMI_Q and BMI_M, as well as between %BF and BMI_Q, and between %BF and BMI_Q. The correlations, however, tend to be higher among females, albeit not significantly, basing on overlapping 95% CIs.

The crosstabulations in Table 4 show the degrees of agreement between weight classifications based on BMI_Q and BMI_M.The proportion of agreement is significantly lower among females (81.0%; 95% CI 73.9%, 88.2%) compared to males (96.0%; 95% CI 91.5%, 100.0%), despite the agreement statistic being substantial (κ=0.7139; 95% CI 0.5969, 0.8309). On the other hand, there is almost perfect agreement between the two weight classifications among males (κ=0.9306; 95% CI 0.7658, 1.0000).

For both sexes, linear and quadratic relationships between %BF and both BMI values (BMI_Q and BMI_M) were analyzed using robust polynomial regression analysis. The adjusted R^2 values, AIC and BIC were determined for full/saturated models and reduced/parsimonious models (see Table 5). The adjusted R^2 values of all models among females were consistently higher than those among males. Additionally, both BMI values and WC were significant predictors of %BF (see Table 6) among females, as opposed to the models for males wherein only BMI values significantly predicted %BF. Among the different BMI_Q models, the quadratic full model consistently had the highest adjusted R^2 values and lowest AIC and BIC values regardless of sex. Likelihood ratio test showed the BMI_Q quadratic full models to fit the data better thanthe BMI_Q linear full models(males: $\chi^2_{df=1}$ = 12.42, $p<0.001$; females: $\chi^2_{df=1}$ = 37.19, $p<0.001$).The samewas demonstrated with the BMI_M quadratic full models relative to their corresponding linear full models(males: $\chi^2_{df=1}$ = 10.68, p= 0.001; females: $\chi^2_{df=1}$ = 26.87, $p<0.001$). However, the BMI_Q quadratic full models had relatively lower AIC and BIC values compared to their BMI_M counterpart models, suggesting better fit of the former to the data.

Table 7 lists the sensitivity, specificity, predictive values, and likelihood ratios of BMI_Q and BMI_M in diagnosing overweight–obesity by %BF (defined as ≥23.1% in males and ≥35.1% in females), using the BMI cutoff of 23 that separates normal from overweight–obese individuals. Consistently, performance is excellent in terms of sensitivity and negative predictive value, but with significantly lower specificity and positive predictive value. Of note, positive predictive value of BMI among females, regardless of BMI type, is significantly lower than that among males.

Figure 2 shows the sex-specific ROC curves for both BMI_Q and BMI_M; all ROC curves have AuROCs>0.90 (summarized in Table 8). The ROC curves for BMI_Q have slightly higher AuROCs than those for BMI_M, but the difference is not statistically significant. The optimal BMI_Q cutoff was determined at 24.2 for males (Sn = 97%, Sp = 82%) and 25.1 for females (Sn = 95%, Sp = 89%), while for BMI_M, the optimal cutoff was 24.5 for males (Sn = 95%, Sp = 82%) and 26.3 for females (Sn = 89%, Sp = 89%).

Table 5. Summary of adjusted R^2 values, Akaike information criteria (AIC) and Bayesian information criteria (BIC) of various sex-specific models regressing %BF on BMI values.

Model	Adjusted R^2	AIC	BIC

	Males	Females	Males	Females	Males	Females
BMI$_Q$ linear full	0.6044	0.7448	312.90	454.59	325.37	467.30
BMI$_Q$ linear reduced	0.6107	0.7475	388.03	452.61	392.61	462.78
BMI$_Q$ quadratic full	0.6733	0.8262	302.48	419.40	317.03	434.66
BMI$_Q$ quadratic reduced	0.6461	0.8108	382.04	520.17	388.91	531.15
BMI$_M$ linear full	0.6113	0.7396	311.87	456.45	324.33	469.17
BMI$_M$ linear reduced	0.6065	0.7425	388.81	454.47	393.39	464.64
BMI$_M$ quadratic full	0.6694	0.8021	303.19	431.59	317.73	446.85
BMI$_M$ quadratic reduced	0.6368	0.7957	383.93	528.98	390.80	539.96

Table 6. Regression analysis summary for BMI$_Q$ and BMI$_M$ quadratic full models for both sexes.

BMI$_Q$ quadratic full model (Males)					
Variable	Observed coefficient, B	95% confidence interval	Bootstrap standard error	Z	*p*-value
(Constant)	–25.96	–46.81, –5.11	10.64	–2.44	0.015
BMI$_Q$	2.93	0.85, 5.02	1.06	2.75	0.006
BMI$_Q^2$	–0.04	–0.07, –0.0002	0.02	–1.97	0.049
Age	0.01	–0.28, 0.31	0.15	0.08	0.934
Smoking	–0.05	–0.41, 0.32	0.19	–0.25	0.806
Alcohol intake	0.14	–0.39, 0.68	0.27	0.53	0.598
WC	–0.04	–0.25, 0.17	0.11	–0.36	0.716

BMI$_M$ quadratic full model (Males)					
Variable	Observed coefficient, B	95% confidence interval	Bootstrap standard error	Z	*p*-value
(Constant)	–23.73	–47.76, 0.30	12.26	–1.194	0.053
BMI$_M$	2.53	0.39, 4.67	1.09	2.31	0.021
BMI$_M^2$	–0.02	–0.07, 0.01	0.02	–1.58	0.113
Age	0.03	–0.24, 0.30	0.14	0.24	0.810
Smoking	–0.06	–0.46, 0.35	0.21	–0.28	0.782
Alcohol intake	0.18	–0.25, 0.62	0.22	0.81	0.416
WC	0.004	–0.20, 0.21	0.11	0.04	0.970

BMI$_Q$ quadratic full model (Females)					
Variable	Observed coefficient, B	95% confidence interval	Bootstrap standard error	Z	*p*-value
(Constant)	–49.39	–71.28, –27.49	11.17	–4.42	<0.001
BMI$_Q$	4.48	2.55, 6.41	0.99	4.54	<0.001
BMI$_Q^2$	–0.08	–0.11, –0.04	0.02	–3.75	<0.001
Age	0.23	–0.02, 0.47	0.12	1.83	0.067
Smoking	0	Omitted			
Alcohol intake	–0.22	–0.88, 0.44	0.34	–0.65	0.515
WC	0.16	0.03, 0.29	0.07	2.34	0.020

BMI$_M$ quadratic full model (Females)					
Variable	Observed coefficient, B	95% confidence interval	Bootstrap standard error	Z	*p*-value
(Constant)	–46.53	–68.32, –24.73	11.12	–4.18	<0.001
BMI$_M$	3.70	1.94, 5.46	0.90	4.12	<0.001
BMI$_M^2$	–0.06	–0.10, –0.03	0.02	–3.48	0.001
Age	0.23	–0.02, 0.48	0.13	1.77	0.076

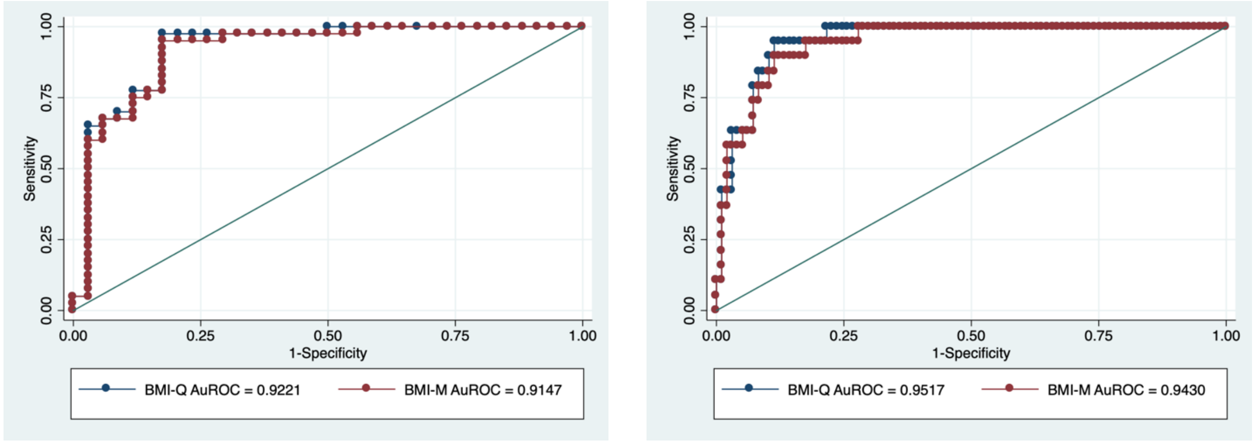
Smoking	0	Omitted			
Alcohol intake	–0.06	–0.75, 0.63	0.35	–0.17	0.861
WC	0.25	0.13, 0.37	0.06	4.00	<0.001

Table 7. Summary of measures of accuracy of BMI$_Q$ and BMI$_M$ in diagnosing overweight–obese.* The 95% CIs are indicated in parentheses.

Measure	BMI$_Q$		BMI$_M$	
	Males	Females	Males	Females
Sensitivity	97.5% (86.8%,99.9%)	100% (82.4%,100%)	97.5% (86.8%,99.9%)	100% (82.4%,100%)
Specificity	58.8% (40.7%,75.4%)	69.1% (58.9%,78.1%)	61.8% (43.6%,77.8%)	61.9% (51.4%,71.5%)
Positive predictive value (PPV)**	73.6% (59.7%,84.7%)	38.8% (25.2%,53.8%)	75% (61.1%, 86%)	33.9% (21.8%,47.8%)
Negative predictive value (NPV)**	95.2% (76.2%,99.9%)	100% (94.6%,100%)	95.5% (77.2%,99.9%)	100% (94%, 100%)
Likelihood ratio (+)	2.37 (1.58, 3.55)	3.23 (2.4, 4.35)	2.55 (1.66, 3.92)	2.62 (2.03, 3.38)
Likelihood ratio (–)	0.04 (0.01, 0.3)	0 (–)	0.04 (0.01, 0.3)	0 (–)

*Overweight–obesity is defined as ≥23.1% BF in males and ≥35.1% BF in females.

**The PPV and NPV were adjusted for known prevalence of overweight-obese based on %BF.



(*a*) (*b*)

Figure 2. Receiver-operator characteristic (ROC) curves with corresponding AuROCs for BMI$_Q$ and BMI$_M$among males (*a*) and females (*b*).

Table 8. Summary of areas under the ROC curve (AuROC) and optimal BMI_Q and BMI_M cutoffs.

Sex	BMI_QAuROC (95% CI)	BMI_MAuROC (95% CI)	Optimal BMI cutoff
Males	0.9221 (0.8538, 0.9903)	0.9147 (0.8441, 0.9853)	BMI_Q: 24.2(Sn = 97%, Sp = 82%) BMI_M: 24.5(Sn = 95%, Sp = 82%)
Females	0.9517 (0.9144, 0.9890)	0.9430 (0.9001, 0.9860)	BMI_Q: 25.1(Sn = 95%, Sp = 89%) BMI_M: 26.3(Sn = 89%, Sp = 89%)

DISCUSSION

The Philippines is a middle-income level country that has moved from an agriculture-based economy to a more manufacturing-based one in the recent years, having an average GDP growth that increased from 4.5% between 2000 and 2009 to 6.3% from 2010 through 2017.[18] As of 2018, its economic growth was pegged at 6.2%, and is forecasted at 6.4% in 2019 and 2020.[19]This country likewise has a large proportion of young people, placing the labor force participation rate at 60.2% as of January 2019.[20]Concurrent with the Philippines' growing industrialization, however, the Filipino diet has progressively moved towards that consisting of processed meats and foods containing high-fructose corn syrup, on top of consuming refined white rice as staple. With majority of the workforce becoming increasingly sedentary, presumably due to more office-based job opportunities, many young adults are at risk for obesity, a condition whichmost health professionals screen for and diagnose by relying on measuring BMI.

While being a widely used and inexpensive anthropometric measure, BMI has its shareof criticisms and drawbacks, particularly important of which is its inability to differentiate between fat and lean body mass, arguably making it an indicator of heaviness rather than adiposity. Thisis exemplified byphysically active occupational groups(policemen, firefighters, athletes), all having considerably greater muscle mass and consequentlyhigher BMIsdespite very low %BF.[21]While squaring the formula's height term in the denominator supposedlyadjustsbody composition to height,[22]analyses of samples from several diverse populations failed to demonstrate independence of BMI (and by extension, %BF) from height.[23]Moreover, BMI underestimates adiposity in individuals with smaller frames while overestimating it in tall people.López-Alvarenga et al.[24]showed that short-statured individuals (women ≤1.50 m, men ≤1.60 m)had significantly higher %BF compared to their taller gender-, age- and BMI-matched counterparts, with wider differencesat BMI ≥25.In light of increasing obesity rates in Southeast Asia, this becomes pertinent to the Filipino population, whose average height approximates the short-stature range.[25]Conversely, tall people tend to have narrower builds, a larger proportion of their body components being skeletal muscle and bone, and legs carrying a larger proportion of their weight, resulting in higher lean-to-fat ratios compared with short-statured individuals.[26]

Believing that the conventional BMI leads short-statured individuals to think they are thinner that they are, and tall people to think the opposite, Lloyd Trefethen proposed a modification to the BMI formula by raising height to a power of 2.5 instead of squaring it. Although no epidemiological evidence supports using an exponent of 2.5 on height,[27]which Trefethen himself disclosed, he explained that using an exponent of 3, as would be the case if weight scaled up the same manner as height,[23,26]would not fit the data well if people's weights were plotted against their heights. He added that a better fit would be obtainedif height was raised to 2.5 instead.[28]The multiplicative factor of 1.3 is based on the square root of 1.69 m, which was set as the average height for adults in the design of the new formula.[16] At this height, the BMI_Q and

$BMI_M$are equal. Keeping weight constant, if BMI_Q and BMI_M were to be plotted against height, the respectivedownsloping curves will intersectat 1.69 m, withthe BMI_Mgraphsteeper than the BMI_Q graph. Naturally, this results in a very high correlation between BMI_Q and BMI_M, as was observed in our study. Thus, for individuals <1.69 m, $BMI_M$is larger than BMI_Q, with the opposite observed for heights >1.69 m.

We observed high correlations between BMI_Q and %BF and between BMI_M and %BF in our study, with the correlationsbeing higher, albeit nonsignificant,among females. This noted sex difference has been demonstrated in prior observational studies,[29-31]and can be explained by the greater fat content among women compared to men for any given BMI,[32]as well as greater lean massand bone density among males. Males with higher BMIs would tend to have lower %BF compared to females with the same BMI range since skeletal muscle is relatively denser (thus heavier) than adipose tissue, again stressingthe inability of BMI to distinguish between lean and fat mass. Despite similar correlations with %BF, there was greater discordance between BMI_Q and BMI_M among females (average BMI_M is almost 1point higher than average BMI_Q, compared to only a 0.1-point difference observed among males), which lead to lower agreement between the two BMI measures in this group, reflected by a step-up in weight classification among 69.2%, 13.0%, and 31.6% of femalesclassified initially as underweight, normal, and overweight, respectively, by BMI_Q. Consistent with the consequence of the modified formula's design, the sole female in our sample with height >1.69 m had BMI_Q larger than BMI_M, while the converse was true for the rest.

In the construction of our sex-specific regression models, factors associated with %BF were included as covariates, namely age,[33,34] smoking,[35,36] alcohol intake,[37,38]andWC.[39] In our study, the full quadratic model fitted the data best for both sexes, basing on information criteria alone.However, available data regarding the shape of the BMI–%BF relationship (that is, whether it is linear[7,40] or quadratic[41,42]) areconflicting, andperhaps can be attributed to observable differences in regional mass and body composition proportions between races or ethnic groups.[43,44]Among Asians, this relationship appears to be quadratic,[42,45] which can be owed to their generally short stature and higher %BF despite normal BMIs.[46-48]In their study on a group of Sri Lankan adults, Ranasinghe et al.[45] demonstrated a statistically significant adjustedR^2increase after addition of the BMI^2 term to each of their sex-specific regression models. This finding is similar to the significant likelihood ratio testswe obtainedfrom assessing the goodness of fit of the linear and quadratic models for each BMI measure stratified by sex.

Also, in our study, WC wasfound to be a significant predictor of %BF, but only among females.It has long been recognized that certain Asian ethnic groups have high prevalence of abdominal adiposity,[49]putting them at risk for metabolic syndrome.Apart from women possessing greater fat content than men for any given BMI, as discussed earlier, Asian women in particular tend to have greater abdominal and visceral adiposity.[50,51]In a study that looked into ethnic differences in abdominal adiposity, Filipino women were found to have the highest visceral adipose tissue content compared to their BMI- and WC-matched Caucasian and African-American counterparts.[52]In the Philippinesetting, indicators of socioeconomic status were found to have a positive relationship with central obesity among young adults, particularly among women, living in the lower-income range.[53]This clearly contradicts what is commonly observed about men tending to accumulate more abdominal fat, and women tending to accumulate it in the thigh and gluteal areas. While the definite reasonfor thisremainsunknown, authors posit a lower capacity of Asians to store fat subcutaneously to be responsible.[50]However, this may as well be a reflection of increasing industrialization and the change in dietary habits that accompanies it.

Using %BF cutoff values of 23.1% in males and 35.1% in females, and a BMI cutoff of 23.0 for both sexes to distinguish between normal and overweight-obese categories, both BMI_Q and BMI_M had comparable measures of diagnostic accuracy. While the two BMI measures performed excellently in terms of sensitivity and NPV based on our data, both had comparably poor specificities, highlighting the inherent inability of BMI to distinguish between lean mass and adipose tissue. Of equal interest is the noticeably poor PPV, particularly among females, indicating that 61.2% of them with BMI ≥23.0 did not satisfy the criteria of being overweight-obese by %BF. Correspondingly, the areas under the ROC curves using a BMI cutoff of 23.0 were 0.8450 for BMI_Q and 0.8090 for BMI_M (not shown in results).Following identification of optimal BMI_Q(25.1) and optimal BMI_M(26.3) values, theseAuROCs improved to 0.9517 and 0.9430, respectively. Using these optimal BMI cutoff values, the PPV improved to 60.7% (not shown in results). As for the male participants, the AuROCs with BMI cutoff of 23.0 were 0.7820 for BMI_Q and 0.7960 for BMI_M (not shown in results).At optimal BMI_Q(24.2) and optimal BMI_M(24.5), the AuROCs improved to 0.9221 and 0.9147, and the PPVs to 86.7% and 86.4%, respectively.A number of studies involving nonathletic adults that used ROC analysis to diagnose the overweight-obese state[30,54-56] demonstrated similar optimal Quetelet BMIs within the range of 24.0 to 28.0, with AuROCs that are at least in the acceptable range. Fortuitously, it is approximately in this BMI range in the general population where its inherent incapacity to distinguish lean mass from adipose composition is probably higher.[57]Comparing these results with our data, however, becomes complicated due to the different methods used in measuring %BF and the absence of standard %BF values for qualifying overfatness. So far, allseem to suggest the need to reevaluatethe utility of current BMI values used in obesity screening, as well as the need to establish a diagnostic %BF in light of results from long-term prospective studies involving Asian populations that investigate health outcomes as a function of BMI or %BF.

In this study, not only were we able to evaluate the ability of Trefethen's modified BMI formula against the traditional Quetelet formula in predicting %BF, we also assessed its performance in discriminating between normal and overweight–obese weight classifications using sex-specific %BF cutoff values. To the best of our knowledge, this is the first study to do so with this particular objective. Apart from the work of Wang et al.,[58]who compared the use of the modified formula in predicting long-term renal graft outcomes with the traditional Quetelet formula, no other studies assessing it for whatever purpose have been done at the time of this writing. Consistent with our study objectives, we were able to show that the BMI_Q and BMI_M are comparable in terms of their measures of diagnostic accuracy and their ability to predict %BF. Perhaps one strength of this study is that recruitment was limited to young adults, which minimizedthe effect of any age-related variation in body composition. Similarly, we restricted our sample to nonathletic individuals, thus avoiding inclusion of participants with large BMIs yet small %BF that may inflate false-positive rates.Welikewise restricted study participation to volunteerswho are of Filipino descent, which diminished the probability of recruiting a sample that is heterogenous in terms of body proportions and composition, thereby avoiding any potential wide within-group variations in BMI and %BF measurements.We also made use of robust polynomial regression analysis in our analysis; compared to conventional multiple regression analysis, it provides better regression coefficients even in the presence of violations to the normality assumption.Lastly, we demonstrated how the weight classification of some participants changed following computation of BMI_M.While examining the association between BMI_M and health complications is beyond the scope of this study, future studies can be undertaken to determine if this change in weight classification has long-term health implications.

Our study also has its share of limitations. Because participation was on a voluntary basis, self-selection bias was inevitably introduced. This may have contributed to an overrepresentation of the overweight and obese weight categories in the sample. Thiscarries potential implications when determining measures of diagnostic accuracy, as some are quite sensitive to the prevalence of the condition of interest (i.e., the overweight/obese state). In our sample, the proportions of overweight and obese participants were indeed vastly larger than that prevalence indicated in the nationwide statistics.[4]To mitigate this, adjustments for overweight-obese prevalence were made in computing for PPV and NPV. Our study also made use ofvoluntary sampling. Due to the non-probability nature of this type of sampling, caution is urged on generalizing our results to the Filipino young adult population.The resultant small sample size we obtained also contributes to this study's limitations. While assessing how well BMI_M predicts or estimates body fat percentage is commensurate with assessing the utility of BMI_M in diagnosing obesity, its sample size would require number that is infeasibly high given our small population size.However, despite a sample size of 190 significantly underpowering our study for the secondary objective, we still obtained results comparable with those obtained in similar prior studies. Moreover, we performed the bootstrap resampling method (with 1000 replications) for the robust polynomial regression analysis in anticipation of the low participation rate. Finally, our study made use of bioelectric impedance analysis (BIA) in quantifying %BF. While dual energy x-ray absorptiometry (DXA) has become more of a "gold standard" in assessing body composition over the past decade, its cost still limits it routine use. A cheaper alternative, BIA indirectly estimates body adiposity by estimating fat-free body mass (by estimated total body water) through the use of electrical impedance and subtracting it from total body weight. It is found to be reliable for use in epidemiological studies,[60,61] provided the necessary preparations are made prior to use (i.e., observing proper body position and avoidance of physical exercise and food or fluid intake beforehand).

In conclusion, both BMI_Q and BMI_M are comparable. Both significantly predicted %BF, with BMI_Qperformingnon-significantly better than the proposed formula in predicting %BF and in discriminating between normal and overweight-obese weight classifications.Both BMI measures performed poorly in terms of specificity, indicating that even with the modifications afforded to the traditional Quetelet formula, BMI_M is unable to differentiate between fat and lean mass. However, given how BMI_M caused the up-classification of weight class among participants <1.69 m tall, we recommend that future studies can be undertaken to determine if this change in weight classification has long-term health implications.

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