Short Communication

Relationships between body size and percent body fat among Melanesians in Vanuatu

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Obesity is a global epidemic, and measures to define it must be appropriate for diverse populations for accurate assessment of worldwide risk. Obesity refers to excess body fatness, but is more commonly defined by body mass index (BMI). Body composition varies among populations: Asians have higher percent body fat (%BF), and Pacific Islanders lower %BF at a given BMI compared to Europeans. Many researchers thus propose higher BMI cut-off points for obesity among Pacific Islanders and lower cut-offs for Asians. Because of the great genetic diversity in the Asia-Pacific region, more studies analyzing associations between BMI and %BF among diverse populations remain necessary. We measured height; weight; tricep, subscapular, and suprailiac skinfolds; waist and hip circumference; and %BF by bioelectrical impedance among 546 adult Melanesians from Vanuatu in the South Pacific. We analyzed relationships among anthropometric measurements and compared them to measurements from other populations in the Asia-Pacific region. BMI was a relatively good predictor of %BF among our sample. Based on regression analyses, the BMI value associated with obesity defined by %BF (>25% for men, >35% for women) at age 40 was 27.9 for men and 27.8 for women. This indicates a need for a more nuanced definition of obesity than provided by the common BMI cut-off value of 30. Rather than using population-specific cut-offs for Pacific Islanders, we suggest the World Health Organization's public health action cut-off points (23, 27.5, 32.5, 37.5), which enhance the precision of assessments of population-wide obesity burdens while still allowing for international comparison.

Key Words: obesity, body weights and measures, body mass index (BMI), adiposity, chronic disease

INTRODUCTION

Defining "normal" weight, overweight, and obesity for specific populations is a difficult task. Obesity refers to excess accumulation of body fat, which the World Health Organization (WHO) identifies as percent body fat (%BF) >25% for men and >35% for women.[1] Obesity is more often classified in terms of body mass index (BMI), the relationship between height and weight calculated as kg/m^2, because height and weight are more commonly collected than %BF.[2] BMI provides a convenient measure for comparing body size among populations and changes within populations over time. However, the measure does not distinguish between differing body proportions or between lean and fat body mass. While a BMI ≥30, the obesity cut-off recommended by the WHO for both men and women, predicts obese levels of body fat relatively well in Caucasians,[3] fat distribution and body mass vary by ethnicity.[2] Thus the BMI cut-off values to define overweight (≥25) and obesity (≥30) based largely on data from Caucasian populations might not be appropriate for other populations. For example, Asians have more body fat, especially abdominal fat, at a given BMI and Pacific Islanders less, compared to Europeans.[4-6] This is important because a person with a low BMI might still be at risk of chronic diseases if %BF is high or if fat is centrally distributed, and a person with a high BMI might be classified as obese when in fact his or her BMI reflects heavy bone or muscle mass.

Recent studies have examined patterns of body fatness and distribution, and their relationship to BMI, among European, Pacific Islander (mostly Polynesian), Asian, and Maori populations.[5,6] We assessed similar measures among Melanesians in Vanuatu, a South Pacific archipelago with about 243,000 residents,[7] which is currently experiencing a health transition from infectious to chronic diseases.[8] Melanesians might be expected to have different body composition patterns than Polynesian Pacific

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Islanders because of their complex genetic history.[9] We examined the relationship between BMI and %BF by bioelectrical impedance analysis (BIA), subcutaneous fat through sum of three skinfolds (SSF), and central obesity through waist to hip ratio (WHR). These analyses provide a comparative basis for other studies of obesity in Melanesia, an area where rapidly increasing obesity rates represent a growing public health concern.[10]

MATERIALS AND METHODS

Anthropometric measurements (height; weight; waist, hip, and upper arm circumferences; tricep, subscapular, and suprailiac skinfolds; and %BF by BIA) were completed in June-July 2007 by researchers from Binghamton University. We sampled 546 "ni-Vanuatu" (Melanesians from Vanuatu) adults, 288 men and 258 women (along with 18 pregnant women excluded from these analyses), from six villages on Ambae, Aneityum, and Efate Island. Villages were chosen because they reflected varying degrees of economic development. This was a convenience sample not nationally representative of urban-rural residence or age but rather reflecting a wide range of body sizes.

Standing height (without shoes) was measured to the nearest 0.1 cm. Weight and foot-to-foot bioelectrical impedance were measured using a Tanita TBF-521 Body Composition Analyzer digital scale (Tanita, Arlington Heights, IL, USA). Percent BF was calculated automatically based on Tanita's proprietary equations for men and women. Each skinfold was measured in mm three times with Lange large skinfold calipers (Cambridge, MD, USA). The means of the three measurements for tricep, subscapular, and suprailiac measurements were summed to provide SSF, a measure of subcutaneous fat. Waist circumference (WC) was measured two centimeters above the naval and hip circumference (HC) at the maximum circumference, to the nearest 0.1 cm. WHR was calculated by dividing WC by HC. Measuring methods were according to standard accepted guidelines.[11]

We used multiple linear regression to analyze relationships among anthropometric measurements separately for men and women, controlling for age. We used the equations from regression analyses to predict the BMI associated with obese levels of body fat (BMI as the dependent variable), and to predict level of body fat associated with WHO public health action BMI values[12] (%BF as the dependent variable). Anthropometric measurements were analyzed separately for men and women using Statistica version 6. Analyses were conducted on the full sample, which included participants ranging in age from 18-80 years, and on a subset of participants ages 30-55.

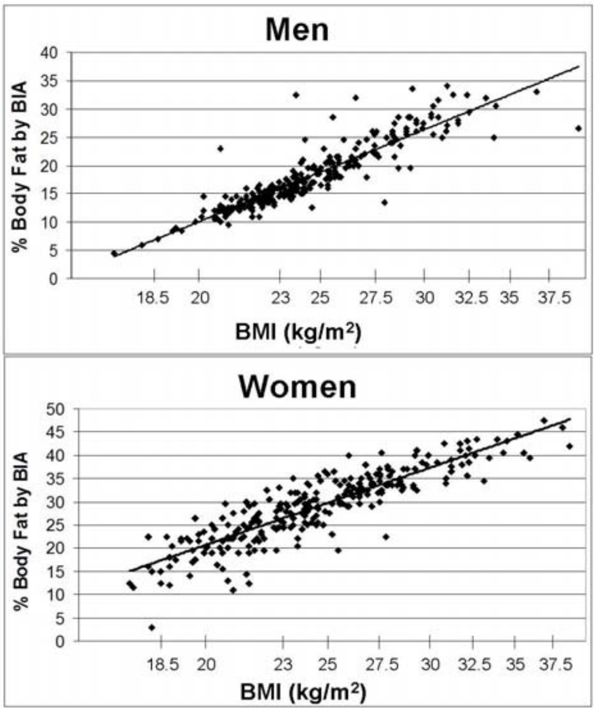

Figure 1. Relationship between BMI and percent body fat by BIA

RESULTS

Sample characteristics

Mean age (SD) for the full sample of men was 37.7 (15.5) and, for women, 35.3 (14.2) years. Mean BMI, %BF, WC, and WHR among men were 24.3 kg/m^2 (3.3), 17.8% (5.7), 81.1 cm (10.3), and 0.868 (0.070), respectively. Mean values among women were 24.7 kg/m^2 (4.2), 28.8% (7.6), 80.8 cm (11.2), and 0.860 (0.077), respectively.

Relationships among anthropometric measurements

Curvilinear relationships were observed between BMI and %BF by BIA, as noted in other studies.[3,5,6,13] In multiple regression analyses, controlling for age, log-transformed BMI predicted %BF relatively well. Adjusted R^2 for the full sample (ages 18-80) were 0.820 for men and 0.779 for women. Among the subset of participants ages 30-55, adjusted R^2 were 0.841 for men and 0.812 for women..

BMI was also a relatively good predictor of WC for the full sample (adjusted R^2=0.824 for men, 0.814 for women) compared to figures for %BF and WC (adjusted R^2=0.757 for men, 0.761 for women) and SSF and WC (adjusted R^2=0.674 for men, 0.653 for women). BMI and %BF predicted SSF slightly better for women (R^2=0.711 and 0.719, respectively) than for men (adjusted R^2=0.667 and 0.691, respectively). Finally, BMI, %BF, and SSF were all poor predictors of WHR for men and especially women, with adjusted R^2 values ranging from only 0.554-0.611 for men, and only 0.311-0.366 for women.

Based on the regression equations for %BF and log-transformed BMI for the subset of participants ages 30-55, we calculated the BMI associated with 25 %BF for men and 35 %BF for women (the %BF values representing the WHO's definition of excess body fat[1]) at age 40. The BMIs at these levels of body fat were 27.9 kg/m^2 (95% CI 27.6-28.3) for men and 27.8 kg/m^2 (95% CI 27.3-28.3) for women. Thus ni-Vanuatu men and women have excess body fat at a lower BMI than is commonly used to define obesity (≥30 kg/m^2). Subsequently, prevalence of obesity in the population would be lower if defined by BMI ≥30 kg/m^2 than if defined by %BF. This is reflected in Table 1, which includes the prevalence of overweight, obesity, and central obesity according to BMI, %BF, WC, and WHR.

DISCUSSION

Body mass index

Obesity is a global epidemic, and standard measures that allow for comparing prevalence among populations over

Table 1. Prevalence of overweight, obesity, and central obesity (% of participants) based on various anthropometric measures and cut-off values among the full sample ages 18-80

	Overweight	Obesity		Central Obesity			
Men	BMI 25-29.9	BMI ≥30	%BF >25	WC 94-101.9 cm (Class 1)	WC ≥102 cm (Class 2)	WHR ≥0.95	WHR ≥1.0
Prevalence (%)	27.8	6.9	14.2	6.3	6.3	14	5.4
Women	BMI 25-29.9	BMI ≥30	%BF >35	WC 80-87.9 cm (Class 1)	WC ≥88 cm (Class 2)	WHR ≥0.8	WHR ≥0.85
Prevalence (%)	30.7	10.9	19.5	24.0	24.4	67.5	45.3

time, such as BMI, provide simple ways to assess risk for many chronic diseases.[12] However, questions regarding the validity of overweight and obesity cut-off values based on statistics from Caucasian populations have led some researchers to employ population-specific cut-offs, especially among Asian and Pacific populations. The great genetic diversity among Pacific Islanders, coupled with insufficient sampling in many populations, complicates the problem of identifying the most appropriate measures and defining cut-off values.

Among Melanesian populations, most researchers have used BMI cut-offs of <18.5 for underweight, 18.5-24.9 for normal weight, 25-29.9 for overweight, and ≥30 for obesity,[14-24] following the WHO's guidelines.[12] However, many other BMI values have also been used. The New Zealand Ministry of Health used BMI cut-offs of ≥26 for overweight and ≥32 for obesity among Pacific Islanders in its 1997 National Nutrition Survey and 2002/03 New Zealand Health Surveys, but used the standard WHO cut-offs in its 2006/07 health survey.[25] Several studies have used cut-off values of <27, 27-31.9, and ≥32,[26,27] or <27 for acceptable weight and >27 for obesity for males.[28,29] For females, cut-off values of <27, 27-31.9, and ≥32 or <27, 27-29.9, and ≥30 have been used.[30] Some researchers have defined underweight as BMI <20.[31] Finally, some researchers define overweight and obesity as body weight exceeding the standard weight for age by 10% and 30%, respectively.[32,33] However, this measurement is dependent on having an acceptable standard for comparison.

The WHO recently evaluated its BMI cut-off values and concluded that Asians have higher cardiovascular disease risk than expected at the BMI cut-off value for overweight (≥25).[12] Based on these and other observations of population body size variance, the expert consultation concluded that further precision was needed in classifying overweight and obesity. Thus in addition to its previous categories (normal 18.5 to <25, overweight or pre-obese ≥25 to <30, obese class I ≥30 to <35, obese class II ≥35 to <40, obese class III ≥40), the WHO added additional public health action points of 23, 27.5, 32.5 and 37.5. Among populations in which observed risk is associated with BMIs lower than 25 (the value commonly associated with overweight), such as some Asian populations, a high prevalence of BMIs above 23 might indicate a need for public health action. Similarly, a high prevalence of BMIs above 27.5 might indicate a need for public health action among populations which have less body fat at a BMI of 25, such as some Pacific Islanders. The expanded range and additional cut-off points allow for enhanced precision in estimating the severity of overweight and obesity. Furthermore, the use of these categories facilitates international comparison of body sizes.[12]

Percent body fat

Body fat can be estimated by several methods; dual-energy X-ray absorptiometry (DXA) is generally considered the most reliable,[2] but it is expensive, more difficult than other methods, and cannot easily be applied to field settings. Skinfold measurements are inexpensive to collect and provide good measures of subcutaneous fat, but predicting total body fat still requires equations that might be biased to specific populations.[34] BIA-based digital scale/body composition analyzers provide relatively inexpensive and portable systems for estimating %BF,[35] and are increasingly used in research and clinical settings.[13] Some problems with BIA include variations based on the level of hydration; identifying the appropriate equations for athletes who have heavy muscle mass, and for the elderly;[3] and a possible need for ethnic-specific equations, which have been proposed for use among adolescents.[36] Unfortunately, we know of no studies validating BIA or the Tanita proprietary equations among Melanesian adults and we thus do not know how %BF estimated by BIA might be biased for our population. Furthermore, we have no measures of hydration levels for our participants, and differences in participants' hydration levels might have introduced variation into our measurements.

While BIA is not the ideal system to measure %BF, especially in populations in which equations have not been validated, the method does hold some benefits. BIA and DXA have been shown to be closely correlated in several studies and BIA provides a good estimator where other measures are not feasible.[13] For example, travel to several of our field sites was difficult and the amount of time available for surveys was limited. BIA-based body composition analyzers are relatively small, portable, and are quick and efficient, which makes them practical to use in field settings. Furthermore, many BIA-based body composition analyzers are battery powered, which was important in our study, since most of our survey sites had no electricity. Because of the importance of %BF in chronic disease risk and the ease of using BIA, the measure has been and continues to be widely applied.

Our study indicates that BMI is a relatively good predictor of %BF by BIA, and BMI is thus a useful measure of obesity among at least one regional population grouping of Melanesians. The correlation between BMI and SSF was less robust in our sample and varied among men and women. This might be due to the three skinfolds chosen (tricep, subscapular, and suprailiac). Body fat distribution patterns are expected to differ from one population to another[5] and between males and females, and the most useful set of measurements for Melanesian men and women might not yet be identified. Therefore, including a greater number and variety of skinfold measurements such as chest, thigh, abdomen, and midaxillary regions might provide a better measure of body fat composition.[34] Although portable and inexpensive, increasing the number and variety of skinfold measurements is still time consuming and labor intensive.

Beyond the problems of available techniques for estimating %BF, defining the cut-off values for obesity based on %BF also remains unclear. While %BF is currently the gold standard, the assigned cut-off values are still an arbitrary definition of obesity,[3] especially since the increase in chronic disease risk is continuous with increasing %BF. The use of population-specific cut-off values, for example >30% BF for Melanesian women,[30] rather than WHO cut-off of 35%, again further complicates the issue.

Central obesity

Central obesity is independently associated with a number of cardiovascular risks, and its measurement is increasingly encouraged in clinical practice and population-based assessments.[1] However, the most accurate measurements of deep abdominal fat, such as magnetic resonance imaging (MRI) or computed tomography (CT), are difficult to employ in most clinical or field settings. External anthropometric measures such as WC provide convenient proxy measurements for deep abdominal fat. The correlations among WC, WHR, and deep abdominal fat vary based on age, ethnicity, and body size and composition,[37-43] and just as BIA is not the most reliable measure of %BF, WC and WHR are not the most reliable measures of central obesity. Nevertheless, WC is independently associated with other risk factors for the Metabolic Syndrome,[44] and it provides an important measure of population risk for a number of chronic diseases.

There is no firm cut-off for defining central obesity among Melanesians. The International Diabetes Federation recommends using ethnic-specific WC cut-off values, and using values established among Caucasians (WC ≥94 cm for me, ≥80 cm for women) if no ethnic-specific values are available. Many researchers also continue to use clinical values from the Adult Treatment Panel III (ATPIII),, ≥102 cm for men, ≥88 cm for women,[44] and report prevalence based on each classification system as "Class 1" and "Class 2" central obesity. There are no ethnic-specific values available for Melanesians. Neither are there firm cut-off values established for WHR among Melanesians. The WHO suggests that WHR >1.0 in men and >0.85 in women is associated with increased chronic disease risk,[45,2] but among Melanesians some researchers have used ≥0.80 or >0.80 for women,[23,30] or ≥0.95 for men and ≥0.85 for women.[29] WC and WHR have both been shown to be sensitive predictors of ischemic heart disease in the Asia-Pacific region,[46] and our studies indicate that central obesity is particularly prevalent among ni-Vanuatu women. The high prevalence of central obesity observed might suggest that both sets of cut-off values are too high for this population, but also warrants further assessment and continued measurement of central adiposity in Vanuatu. Where time and resources are limited, collecting measurements for central obesity might be recommended over other measures such as SSF.

Obesity in the Asia-Pacific Region

Defining obesity in the Asia-Pacific region is particularly problematic because of the wide range of diversity in body composition among groups,[5] from South Asians who have high levels of abdominal fat at lower BMIs than other populations,[47,48] to Polynesians, who are among the largest people in the world, with a high prevalence of

Table 2. Estimated percent body fat at WHO recommended[10] BMI values for adults at age 40

BMI	Percent body fat from various samples					
Males	Ni-Vanuatu† ages 18-80	Ni-Vanuatu† ages 30-55	European‡	Maori‡	Pacific Islander‡	Asian‡
20	10.4	10.2	11.2	9.6	9.7	22.1
23	15.9	16.0	17.4	15.8	14.8	27.3
25	19.2	19.5	21.1	19.5	17.9	30.4
27.5	23.0	23.5	25.4	23.8	21.4	33.9
30	26.5	27.1	29.2	27.7	24.6	37.1
32.5	29.7	30.4	32.8	31.2	27.5	40.0
35	32.6	33.5	36.1	34.5	30.3	42.7
37.5	35.3	36.4	39.1	37.6	32.8	45.3
Females						
20	20.5	20.9	25.8	28.1	26.5	34.9
23	26.3	26.5	31.7	32.2	30.6	39.0
25	29.7	29.8	35.2	34.6	33.0	41.5
27.5	33.7	33.6	39.1	37.4	35.8	44.3
30	37.2	37.0	42.8	40.0	38.4	46.8
32.5	40.5	40.2	46.1	42.3	40.7	49.2
35	43.6	43.1	49.2	44.5	42.9	51.4
37.5	46.4	45.8	52.1	46.5	44.9	53.4

† This study; ‡ Rush et al., 2009

body fatness, but also heavy bone and skeletal muscle mass.[5] Based on complex histories of migration, isolation, and adaptation to a range of environments,[9] we should expect to see population diversity in body composition, even among groups that are usually classified together as Pacific Islanders.

Recently, Rush et al.[5] assessed %BF through DXA among 933 European, Asian Indian, Maori, and Pacific Island (primarily Samoan) men and women ages 18-80. While the differences in estimating %BF introduce some error, their sampled populations provide good comparisons for our Melanesian sample. We estimated %BF at the WHO-recommended public health action point BMI levels for these samples, holding age constant at 40 years. Estimates for ni-Vanuatu men and women are based on regression equations derived from both the entire sample (18-80 y), as well as a subset of participants (30-55 y) which might provide more precise estimates for the middle-aged. Regression equations for the ni-Vanuatu samples were: for men ages 18-80, %BF = 91.365($\log_{10}$BMI) + 0.020×age – 109.274; for men ages 30-55, %BF = 95.929 ($\log_{10}$BMI) + 0.046×age – 116.444; for women ages 18-80, %BF = 94.792($\log_{10}$BMI) – 0.031×age – 101.539; for women ages 30-55, %BF = 91.295($\log_{10}$BMI) – 0.076×age – 94.822.

Ni-Vanuatu men had greater %BF (Table 2) than Rush and colleagues' Pacific Islanders, less than European and Asian Indian participants at all BMI values, and less than Maori at all but the lowest BMI values. Ni-Vanuatu women in our study, on the other hand, had lower %BF than all the groups in Rush et al.'s study at low BMI, but a steeper regression slope (resembling that of Europeans) than Maori, Pacific Islander, or Asian Indian women. At BMI values greater than 30, ni-Vanuatu women had levels of body fat similar to or exceeding Maori and Pacific Island women.

These figures highlight the importance of the public health action points recommended by the WHO[12] to more accurately classify overweight and obesity. Classifying obesity based on the higher BMI cut-off values (≥32) used for Polynesians[25] and other Pacific Islanders[26,27] might underestimate risk among Melanesian men and women, who have greater %BF than Polynesians at a given BMI and obese levels of body fat at a BMI of 27.9 and 27.8, respectively. Furthermore, because %BF increases particularly rapidly with BMI among ni-Vanuatu women, a more subtle classification system might be necessary if public health action is to be taken appropriately early.

Implications for health care and research

The prevalence of obesity is an important public health measure of chronic disease risk, and the accuracy of common measurements to estimate its prevalence, such as BMI, has important implications for population health. For example, in developing countries where rates of obesity are increasing rapidly,[49] underestimating the true prevalence of obesity could delay action during the early stages of an emerging public health problem when prevention measures might be most productively employed. Similarly, in developed countries with high levels of immigration, a lack of precision in defining obesity could underestimate risk among ethnic minorities – populations that might be particularly vulnerable because of changes in diet and activity patterns.[50] Where time and resources allow, collecting multiple measures, including %BF and WC or WHR, is preferable. For Melanesian men and women, BMI provides a relatively good predictor of %BF and the use of the recommended public health action points provides a more nuanced picture of risk that is still appropriate for international comparison.

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AUTHOR DISCLOSURES

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Short Communication

Relationships between body size and percent body fat among Melanesians in Vanuatu

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瓦努阿圖的美拉尼西亞族人的體型與體脂肪百分率之關係

肥胖屬於全球流行病，但對於不同的族群，應各有合適的測量定義，以作為全球風險的正確評估。肥胖是指過量的體脂肪，但較常以身體質量指數(BMI)作為其定義標準。各族群間身體組成各異。在相同的 BMI 下，與歐洲人相比，亞洲族裔有較高的體脂肪比例，而太平洋群島族裔則有較低的體脂肪百分率。許多研究學者因此提議對於太平洋群島族裔，應以較高的 BMI 切點來定義肥胖，而對於亞洲族裔，則應用較低的 BMI 切點。由於在亞太地區有較高的遺傳多樣性，因此需要更多對於不同族群的 BMI 與體脂肪百分率之相關性的研究。測量南太平洋瓦努阿圖的 546 位美拉尼西亞族人的身高、體重及三頭肌、肩胛骨下、髂骨上方的皮脂厚度，還量度腰圍及臀圍，且利用生物電阻抗法來估量體脂肪百分率。統計分析體位測量指標之間的相關性，並與亞太地區其他族群的資料進行比較。在本研究樣本中，BMI 對體脂肪百分率的預測相當良好。以體脂肪百分率(男性高於 25%，女性高於 35%)定義肥胖，並依據迴歸分析找出相對應的 BMI 值，結果顯示對 40 歲者而言，男性為 27.9，女性為 27.8。這結果指出，需要一個更精細的肥胖定義，而不是通用切點 BMI=30。為提高全民肥胖負擔評估之精確度，並考慮到國際間的比較，我們建議採用世界衛生組織的公共衛生行動增加的切點(23、27.5、32.5 及 37.5)，而非使用特定族群的切點來評估太平洋群島族裔。

關鍵字：肥胖、體重與度量、身體質量指數、脂肪過多、慢性疾病