THE STUDY ON GLOBAL AGEING AND ADULT HEALTH (SAGE): BODY COMPOSITION MEASURES AMONG AGEING POPULATIONS

by

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A THESIS

Presented to the Department of Biology
and the Robert D. Clark Honors College
in partial fulfillment of the requirements for the degree of
Bachelor of Science

June 2015

An Abstract of the Thesis of

Austin Alexander Wong for the degree of Bachelor of Science
in the Department of Biology to be taken June 2015

Title: The Study on global AGEing and adult health (SAGE): Body Composition Measures among Ageing Populations

Approved: ______________________________

Dr. James Josh Snodgrass

As the global obesity epidemic continues to affect high-income countries, low- and middle-income countries have also begun to experience increases in overweight and obesity prevalence. Both overweight and obesity are major risk factors for many chronic diseases such as diabetes, cancer, and cardiovascular disease. Body mass index (BMI) is one common measure used to predict obesity-related health risks. However, because it estimates general adiposity instead of abdominal obesity, and does not distinguish between fat and lean mass, BMI is not a completely reliable predictor of cardiovascular and metabolic risk. Previous studies have generally found that measures of central obesity, including waist circumference (WC), to be better predictors of cardiovascular and metabolic risk than BMI, but no conclusion has been reached regarding the optimal measure of body composition. Furthermore, few studies have examined how body composition measures differ across various populations in older adults (≥50 years). The current study uses data from the World Health Organization Study on global AGEing and adult health (SAGE), a longitudinal study of nationally representative samples from older adults in six middle income countries (China, Ghana, India, Mexico, Russian Federation, and South Africa). This study examines associations among body composition measures (BMI, WC, and body adiposity index [BAI]) across age category, sex, and country. Furthermore, this study investigates associations between body composition measures and hypertension. Results indicate variability in body composition trends across age category, sex, and country. In general, both mean BMI and overweight and obesity prevalence were greater in 80+ age categories compared to younger age categories while mean BAI, mean WC, and increased risk (for obesity-related health diseases) prevalence were relatively similar across age categories. Logistic regression analyses were used to evaluate BMI, WC, and BAI as predictors of hypertension while controlling for covariates such as age, sex, smoking, drinking, and physical activity. All three body composition measures were fairly similar in their ability to predict hypertension. These findings suggest that BMI could be underestimating obesity-related health risks in population studies of older adults with the greatest underestimation in adults 80 years and older.

Acknowledgements

I would like to thank Josh Snodgrass and Melissa Liebert for helping me to fully examine this specific topic and consider the various perspectives and contexts related to this subject matter. I would like to thank the members of my committee - Josh Snodgrass, Melissa Liebert, and Samantha Hopkins - for all of their time and help throughout the thesis process from brainstorming to analyzing data to understanding statistical methods to writing and presenting. I would like to thank Paul Kowal and all participants in the study. Finally, I would like to thank my family and friends, especially my loving mom and my best friend Leo, for supporting me and believing in me throughout my college education.

SAGE was supported by NIH NIA Interagency Agreement YA1323-08-CN-0020, the NIH grant R01-AG034479, and the University of Oregon.

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Background

Among older adults, obesity increases the risks for cardiovascular and metabolic diseases such as type 2 diabetes, hypertension, stroke, heart disease, and metabolic syndrome (Salihu et al., 2009). Because actual measurement of body fat is difficult, invasive, and expensive, body mass index (BMI) is frequently used in population-based research as a predictor of obesity-related health risks. However, BMI does not distinguish between fat and lean mass, and is more strongly associated with subcutaneous fat than visceral fat (Janssen et al., 2002), the most pathogenic type of fat, thus reducing its ability to accurately predict health risks (Figure 1). Further, previous research has found that it is possible for adults to maintain a normal BMI, yet increase their waist circumference (WC) over time; this makes BMI a less accurate predictor of cardiovascular and metabolic risk in older adults. While measures of central obesity have been found to be better indicators of cardiovascular disease than BMI, debate continues over the optimal measure of central adiposity for use in population studies such as in the fields of epidemiology and anthropology where expensive lab-based techniques cannot realistically be used.

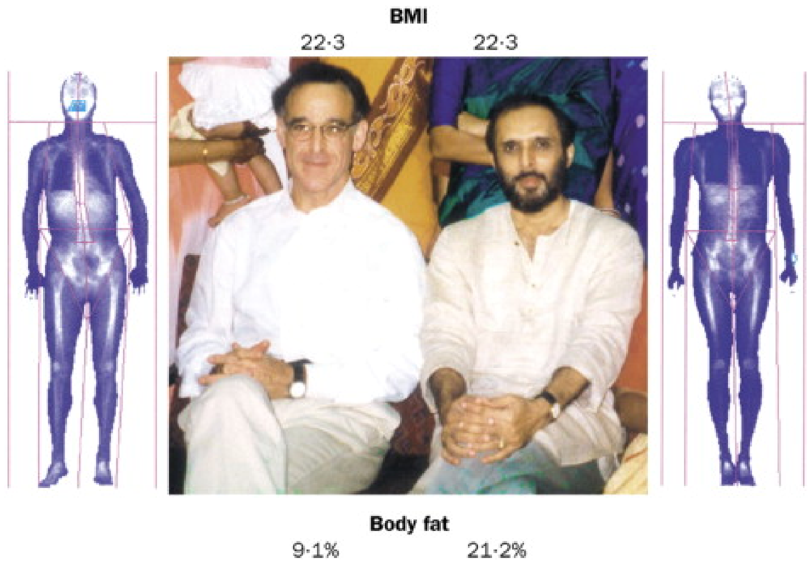

Figure 1: BMI vs. Body Fat.

Two individuals with very different body types and body fat percentages can have the same BMI because BMI does not distinguish between fat and lean mass. Dual-energy X-ray absorptiometry images are shown at each end. Reprinted from The Lancet, Vol. 363, Yajnik, Chittaranjan S. and Yudkin, John S., “The Y-Y paradox,” p. 163, Copyright (2004), with permission from Elsevier.

Many studies have investigated body composition measures by grouping together adults into one category of subjects 18 years and older. As a result, few studies have compared the accuracy and usefulness of body composition measures in older adults (≥50 years). In general, older adults are shorter than younger adults due to shrinkage of the spine, which can lead to overestimation of BMI in older adults (Snijder et al., 2005). However, this limitation of BMI does not occur in body composition measures without height, such as WC. Additionally, in a process known as sarcopenia, the amount of lean body mass decreases with age, contributing to a relatively greater amount of body fat found in older adults compared to younger adults at equivalent BMIs (Snijder et al., 2005). Finally, while obesity increases cardiovascular and metabolic risk in older adults, increased adiposity may be protective against death in individuals over 85 years, particularly in hospitalized patients (Inelmen et al., 2003). Therefore, it is of particular interest to study various body composition measures in older adults in order to better assess which measures might be most useful in population studies that include older adults.

Additionally, few studies have investigated the trends of body composition measures among older adults in low- and middle-income countries (LMICs). In their review of global obesity, Malik and colleagues (2012) found a positive correlation between obesity prevalence and the initial stages of economic growth found in LMICs. Part of this correlation could stem from nutritional and lifestyle changes during such an economic transition while continuing to have little access to the health services and education that wealthy countries can provide. Moreover, urban growth has been associated with obesity in the US, and 93% of urban growth globally is expected to occur in LMICs (Malik et al., 2012). Thus, LMICs are particularly important to investigate in studies of obesity and body composition measures.

Research Questions and Hypotheses

This study examines how body composition measures (BMI, WC, body adiposity index [BAI]) differ across age categories (50-59, 60-69, 70-79, 80+ years), sex (male, female), and countries (China, Ghana, India, Mexico, Russian Federation, South Africa). Furthermore, this study investigates associations between body composition measures and hypertension (high blood pressure).

I hypothesize that:

1. Weighted prevalence of obese and overweight BMI as well as increased risk WC will be significantly lower in the 80+ age category compared to 50-59, 60-69, and 70-79 age categories for males and females in all countries.

2. Average BMI, WC, and BAI values will be significantly lower in the 80+ age category compared to 50-59, 60-69, and 70-79 age categories for males and females in all countries.

3. Average male BMI, WC, and BAI values will significantly differ from female values for all age categories in all countries.

4. Average BMI, WC, and BAI values will significantly differ across country for males and females in all age categories.

5. WC and BAI will be stronger predictors than BMI for hypertension.

Methods

The Study on global AGEing and adult health (SAGE)

This study used Wave 1 data (2007-2010) from the World Health Organization (WHO) Study on global AGEing and adult health (SAGE; http://www.who.int/healthinfo/sage/en/), a longitudinal epidemiological study of nationally representative samples from older adults (≥50 years old) in six middle income countries (China, Ghana, Mexico, India, Russian Federation, and South Africa) with a smaller sample of adults aged 18-49 years in each country for comparison (Kowal et al., 2012). However, the Russian Federation recently moved up to high-income classification following changes in the World Bank's classification of the world's economies based on estimates of gross national income (GNI) per capita (World Bank, 2013). Nonetheless, these six countries provide an economically, geographically, and culturally diverse group to study the effects of aging on health, and one that includes the two most populous countries in the world (China and India).

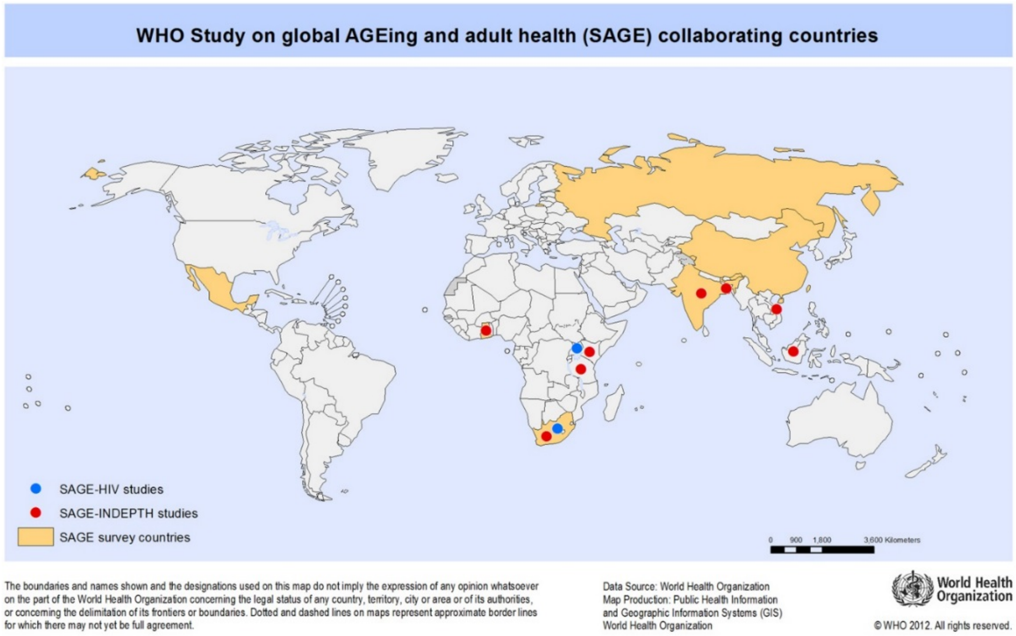

Figure 2: SAGE Study Map.

Nationally representative studies are indicated in yellow while local non-nationally representative studies are indicated by blue and red dots. Reprinted from WHO by WHO, 2012, Retrieved from http://www.who.int/healthinfo/sage/sage_001.jpg?ua=1. Copyright [2012] by WHO.

SAGE collected a wide variety of data on participant health through a series of questions via face-to-face interviews. Multistage cluster sampling strategies were used to sort individuals into one of two different clusters (“50+ households” or “18-49 households”) based on their age (Kowal et al., 2012). Clusters were then randomly selected. Sample datasets were weighted by household and individual to provide even sampling. Additionally, the SAGE dataset is proportional to population size and contains over 34,000 participants aged 50 years and older, and over 8000 participants aged 18-49 years (Kowal et al., 2012).

SAGE instruments and methods were adapted from those used by the World Health Survey, the US Health and Retirement Survey, and the English Longitudinal Study of Ageing. Because these three surveys take place in high-income countries, this adaptation of instruments and methods allows researchers to directly compare SAGE results from middle-income countries to results from high-income countries in the aforementioned studies.

Height, weight, WC, hip circumference, and blood pressure collected from the SAGE surveys were used to calculate body composition measures and determine the presence or absence of hypertension in this study (Appendix Figures 1 and 2).

Body Composition Measures: Body Mass Index (BMI), Waist Circumference (WC), and Body Adiposity Index (BAI)

Body mass index was defined as the quotient of an individual's mass in kilograms and the square of his or her height in meters:

$$BMI = \frac{mass\ (kg)}{(height\ (m))^2} = \frac{mass\ (lbs)}{(height\ (in))^2} \times 703$$

This study used established WHO cut-off values for BMI categories as follows: underweight (<18.5 kg/m^2), normal (18.5-24.9 kg/m^2), overweight (25.0-29.9 kg/m^2), and obese (≥ 30.0 kg/m^2) (WHO, 2000). Modified BMI cut-off values were used for China and India because the relationships among BMI, body fat percentage, and health risks are different for Asian populations in comparison to other populations (WHO, 2004). Therefore, the categories for China and India were as follows: underweight

(<18.5 kg/m^2), normal (18.5-22.9 kg/m^2), increased risk (23.0-27.5 kg/m^2), and higher high risk (≥ 27.5 kg/m^2) (WHO, 2004). Additionally, BMI was analyzed as a continuous variable.

Waist circumference was "measured at the midpoint between the lower margin of the least palpable rib and the top of the iliac crest" with the tape parallel to the floor (WHO, 2011: 7). This study also used established WHO categories and cut-off values for WC: normal (<94 cm) and increased risk (≥ 94 cm) for males, and normal (<80 cm) and increased risk (≥ 80 cm) for females (WHO, 2011). Similarly, modified WC cut-off values were used for China and India, which only altered the cut-off values for males: normal (<90 cm) and increased risk (≥ 90 cm) (IDF, 2006). WC was also analyzed as both a categorical and continuous variable.

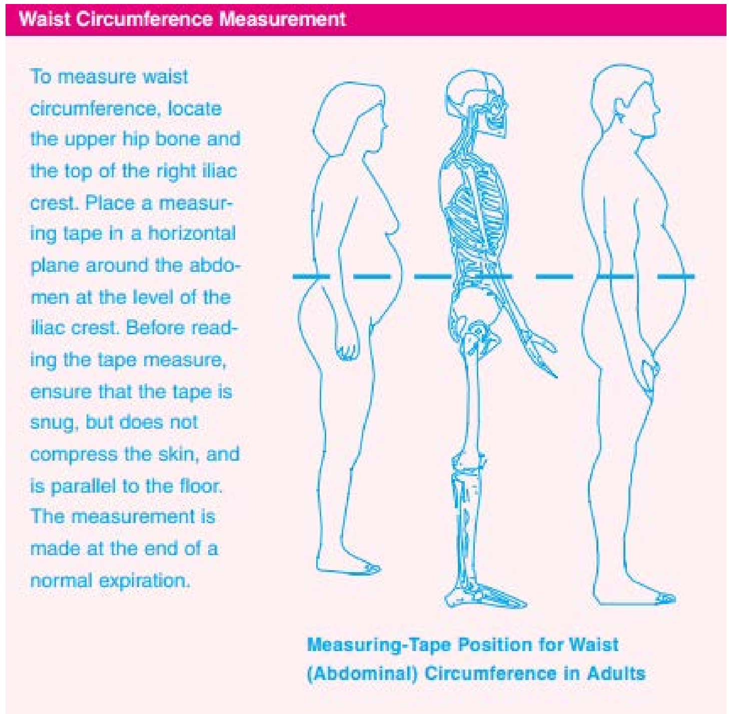

Figure 3: Waist Circumference Measurement.

Reprinted from "The Practical Guide: Identification, Evaluation, and Treatment of Overweight and Obesity in Adults" (NIH Publication No. 00-4084), by U. S. Department of Health and Human Services, National Institutes of Health, National Heart, Lung and Blood Institute, 2000, p. 9. Retrieved Feb. 16, 2015, from http://www.nhlbi.nih.gov/files/docs/guidelines/prctgd_c.pdf

Body Adiposity Index is a relatively new index for body adiposity that strongly correlates with body fat percentage in both males and females (Chang et al., 2013). Furthermore, it has been validated as an estimation of body adiposity in older adult populations (Chang et al., 2013). BAI uses hip circumference and height in its calculation:

$$BAI = \frac{hip\ circumference\ (cm)}{(height\ (m))^{1.5}} - 18$$

López et al. (2012) determined cutoff values of 27 and 32 for classifying obesity in males and females, respectively, using BAI. However, much is still unknown about the scope of BAI; there currently are no WHO recommendations or standardized cutoff points for BAI with regards to ethnicity and levels of obesity. Consequently, BAI was only analyzed as a continuous variable. Additionally, following the protocol of Chang and colleagues (2013), a modified equation was used when an individual's BAI calculated using the above equation was greater than 31.3:

$$Modified\ BAI = \frac{0.4\ \times hip\ circumference\ (cm)}{(height\ (m))^{1.5}} + 24$$

Blood Pressure

A series of three measurements of both systolic BP (SBP) and diastolic BP (DBP) were measured during the interview using a Boso Medistar Wrist Blood Pressure Monitor Model S. Following the protocol of Lloyd-Sherlock and colleagues (2014), hypertension was considered to be present if the mean of the last two measurements was ≥140 mmHg for SBP or ≥90 mmHg for DBP and/or if respondents were currently taking antihypertensive medication.

Statistical Analysis

Only subjects aged 50 and older were used in the present study. Tests of normality were conducted, and outliers were identified from initial analyses. Extreme outliers were classified with interquartile ranges (IQRs) for each variable by age category, sex, and country following Larson (2006), and excluded from subsequent analysis. These outliers were most likely a result of errors in measurement or data entry. Given the total sample size, the overall impact of removing the outliers is minimal and provides a more accurate population estimate. All analyses were conducted using SPSS 21.0, and results were considered significant at $p < 0.05$.

Hypothesis 1

Weighted prevalence values were calculated by age category, sex, and country for BMI categories (underweight, normal, overweight/increased risk, obese/higher high risk) and WC categories (normal, increased risk). Weighting the data, which allowed certain data points to influence the means more than others, was performed in order to make the samples representative of the actual populations with respect to country, sex, and age.

Hypotheses 2, 3, and 4

A three-way ANOVA test was used to examine the main effects of age category, sex, and country as well as their interactions. Simple effects tests were also conducted to analyze the effect of sex at each level of age category (50-59, 60-69, 70-79, 80+) and country (China, Ghana, India, Mexico, Russian Federation, and South Africa), the effect of age category at each level of sex (male and female) and country, and the effect of country at each level of age category and sex. These tests provide an opportunity to examine the effect of one independent variable at individual levels of the other independent variable. Due to multiple comparisons, all analyses used a Bonferroni correction method.

Hypothesis 5

Logistic regressions were used to predict the likelihood of being classified with hypertension while controlling for covariates typically used in hypertension research (age, sex, physical activity, smoking, and drinking; Janssen et al., 2004). Each of the control variables was measured via self-reporting as part of the SAGE individual questionnaire (Appendix Figures 3, 4, and 5).

Results

Unweighted samples sizes are displayed in Table 1, separated by country and sex.

	Participants		
Country	**Male**	**Female**	**Total**
Mexico	781	1234	2015
Ghana	2158	1975	4133
India	3188	3116	6304
China	5711	6577	12288
South Africa	1459	1956	3415
Russian Federation	1015	2042	3057
Total	**14318**	**16911**	**31229**

Table 1: Unweighted Sample Sizes by Country and Sex

Hypothesis One – Weighted Prevalence Values

MALES:

<u>BMI</u>

Overweight prevalence was lower in the 80+ age category compared to the 50-59, 60-69, and 70-79 age categories in all countries except Russian Federation where overweight prevalence did not vary throughout the age categories. Obesity prevalence was lower in the 80+ category for Mexico, South Africa, Russian Federation, and China while it did not differ throughout the age categories in India and Ghana. Overweight prevalence varied from 10.4% (India 80+) to 64.8% (Mexico 50-59), while obesity prevalence varied from 2.8% (India 60-69) to 43.5% (South Africa 60-69).

WC

Increased risk prevalence was lowest in the 80+ age category in all countries except in South Africa (2nd lowest to 50-59) and India (2nd lowest to 70-79). Increased risk prevalence varied from 14.2% (India 70-79) to 65.7% (Mexico 60-69).

FEMALES:

BMI

Overweight prevalence was lowest in the 80+ age category for all countries except in South Africa where it was the second highest prevalence. Obese prevalence was lowest in the 80+ age category for all countries. Overweight prevalence varied from 2.9% (India 80+) to 46.2% (China 50-59). Obese prevalence varied from 3.1% (India 80+) to 56.7% (South Africa 60-69).

WC

Increased risk prevalence was lowest in the 80+ age category in Mexico, Ghana, and India. In Russian Federation and China, it was second lowest in the 80+ age category (50-59 was lowest). In South Africa, increased risk prevalence was greatest in the 80+ age category. Increased risk prevalence varied from 34.5% (India 80+) to 96.7% (Mexico 50-59).

Hypothesis Two – Examining Differences across Age Categories by Sex and Country

MALES:

Mean BMI, WC, and BAI values for males (by age and country) are presented in Table 2. India had the lowest mean BMI, WC, and BAI for all age categories except for 80+ BAI (Ghana had the lowest). South Africa had the highest mean BMI for all age categories. Mexico had the highest mean WC for all age categories. Mexico had the highest mean BAI for 50-59 and 80+ age categories while South Africa had the highest mean BAI for 60-69 and 70-79 age categories. Mean BMI varied from 18.94 (India 80+) to 28.09 (South Africa 60-69), mean WC varied from 80.40 (India 80+) to 99.44 (Mexico 70-79), and mean BAI varied from 24.49 (India 60-69 and 70-79) to 34.25 (South Africa 70-79).

	MEXICO			GHANA			SOUTH AFRICA		
Age Category	Mean BMI	Mean WC	Mean BAI	Mean BMI	Mean WC	Mean BAI	Mean BMI	Mean WC	Mean BAI
50-59	27.60	99.27	33.01	22.81	83.40	24.71	28.05	87.86	32.11
60-69	27.41	99.34	32.52	22.20	82.00	24.68	**28.09**	88.76	33.22
70-79	26.87	**99.44**	33.72	21.81	82.13	24.77	27.98	88.95	**34.25**
80+	25.39	94.55	34.20	21.03	80.63	24.64	27.94	89.19	33.77
	RUSSIAN FEDERATION			**INDIA**			**CHINA**		
Age Category	Mean BMI	Mean WC	Mean BAI	Mean BMI	Mean WC	Mean BAI	Mean BMI	Mean WC	Mean BAI
50-59	27.21	94.37	27.16	20.71	82.43	24.61	23.55	83.97	27.06
60-69	27.07	93.99	26.83	19.85	81.57	**24.49**	23.53	84.80	28.12
70-79	27.05	93.64	29.76	19.61	80.88	**24.49**	23.15	84.81	28.81
80+	26.69	92.85	30.04	**18.94**	**80.40**	24.67	22.57	84.48	29.08

Table 2: Mean Body Composition Measures for Males

Red highlighting indicates the maximum value for a body composition measure within an age category among all countries. Bold text accompanied by red highlighting specifies maximum values among all age categories. Blue highlighting indicates the minimum value for a body composition measure within an age category among all countries. Bold text accompanied by blue highlighting specifies minimum values among all age categories.

BMI

In Mexico, Ghana, and China, the 80+ age category had a significantly lower BMI than all other age categories except the 70-79 category (Figure 4). For Indian males, only the 80+ and 50-59 age categories were significantly different. Additionally, no significant differences were found in South Africa and Russian Federation.

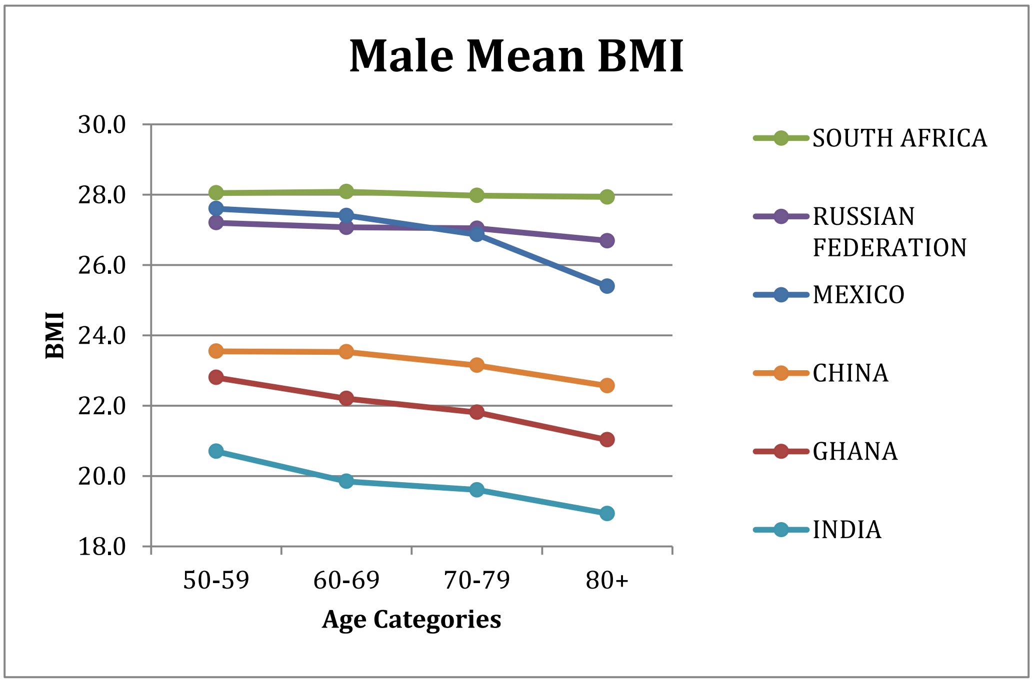

Figure 4: Male mean BMI across age categories by country.

WC

Mexico was the only country whose 80+ age category had a significantly smaller mean WC than all other age categories (Figure 5). The 80+ age category for Ghana was only significantly smaller than the 50-59 age category. No significant differences were found for India, Russian Federation, South Africa, and China.

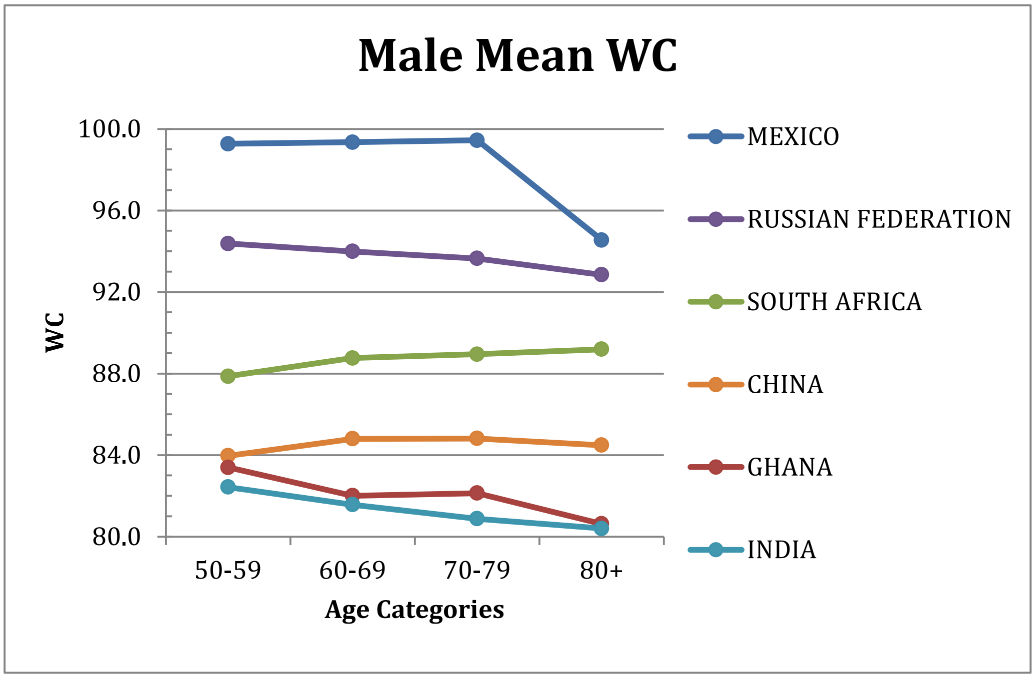

Figure 5: Male mean WC across age categories by country.

BAI

Russian Federation's 80+ age category was significantly greater than the 60-69 age category, while China's 80+ age category was significantly greater than the 50-59 age category (Figure 6). Mexico, South Africa, Ghana, and India had no significant differences among each of their age categories.

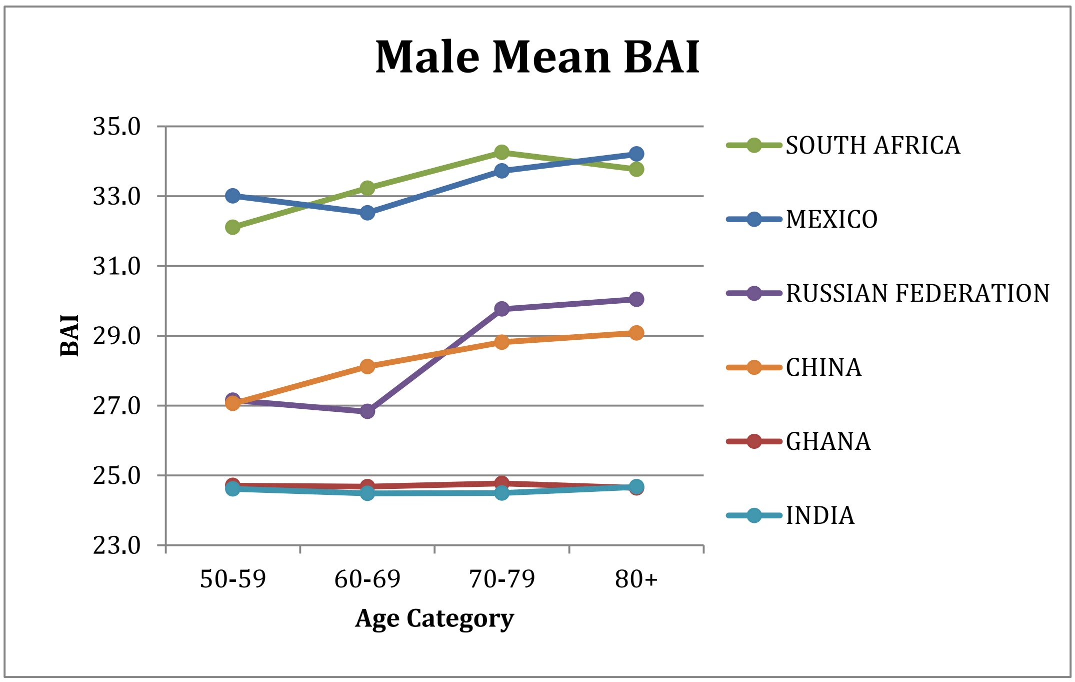

Figure 6: Male mean BAI across age categories by country.

FEMALES:

Mean BMI, WC, and BAI values for females (by age and country) are presented in Table 3. India had the lowest mean BMI and WC for all age categories, and Ghana had the lowest mean BAI for all age categories. South Africa had the highest mean BMI for all age categories, and Mexico had the highest mean WC for all age categories except 80+ (Russian Federation had the highest). Finally, Mexico had the highest mean BAI for all age categories. Mean BMI varied from 19.30 (India 80+) to 31.08 (South Africa 50-59). Mean WC varied from 77.69 (India 80+) to 97.25 (Mexico 60-69). Mean BAI varied from 30.65 (Ghana) to 46.34 (Mexico 70-79).

	MEXICO			**GHANA**			**SOUTH AFRICA**		
Age Category	Mean BMI	Mean WC	Mean BAI	Mean BMI	Mean WC	Mean BAI	Mean BMI	Mean WC	Mean BAI
50-59	29.51	96.25	45.69	25.27	88.42	33.56	**31.08**	91.16	38.76
60-69	29.69	**97.25**	45.94	24.09	87.55	33.29	31.04	92.44	40.74
70-79	28.58	95.78	**46.34**	22.29	84.44	31.78	29.61	92.11	40.33
80+	26.43	92.78	45.81	21.15	80.96	**30.65**	28.40	89.17	39.99
	RUSSIAN FEDERATION			**INDIA**			**CHINA**		
Age Category	Mean BMI	Mean WC	Mean BAI	Mean BMI	Mean WC	Mean BAI	Mean BMI	Mean WC	Mean BAI
50-59	29.90	93.92	39.98	21.36	82.20	34.70	24.27	83.42	35.90
60-69	30.13	95.98	41.72	20.66	80.93	34.47	24.09	84.40	37.52
70-79	29.12	95.40	41.30	20.13	80.43	34.61	23.83	85.12	38.85
80+	27.95	94.09	40.92	**19.30**	**77.69**	34.02	22.77	84.11	40.21

Table 3: Mean Body Composition Measures for Females

Red highlighting indicates the maximum value for a body composition measure within an age category among all countries. Bold text accompanied by red highlighting specifies maximum values among all age categories. Blue highlighting indicates the minimum value for a body composition measure within an age category among all countries. Bold text accompanied by blue highlighting specifies minimum values among all age categories.

BMI

The 80+ age categories in Mexico, Ghana, China, and Russian Federation had significantly smaller mean BMIs than all other age categories (Figure 7). Similarly, India’s and South Africa's 80+ age category had a significantly smaller mean BMI than those in the 50-59 and 60-69 age categories but not the 70-79 age category.

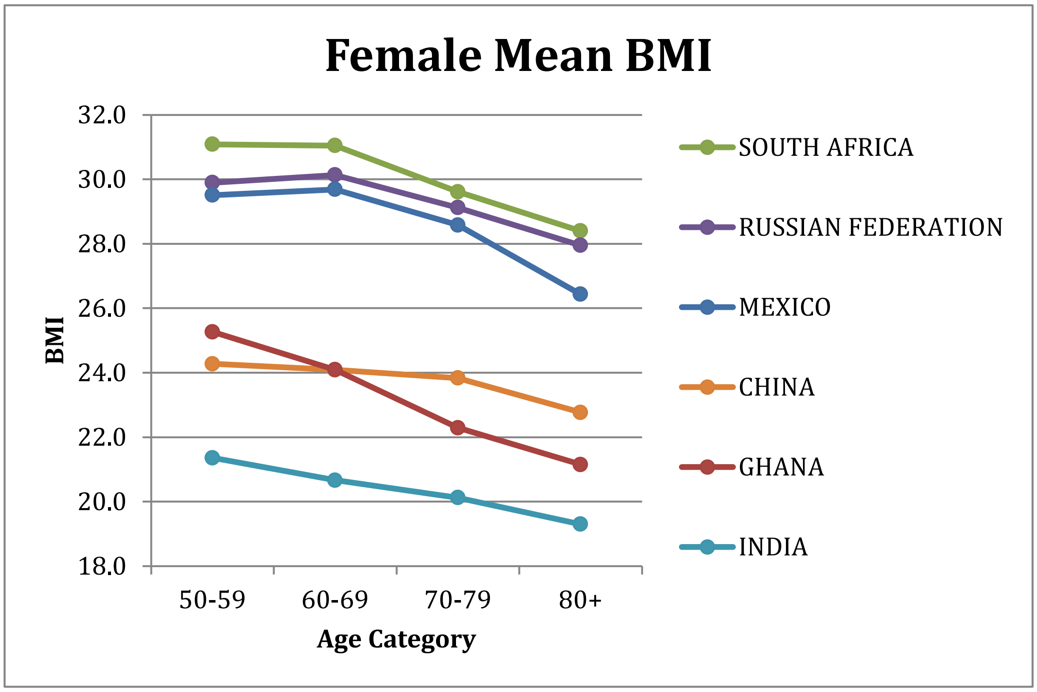

Figure 7: Female mean BMI across age categories by country.

WC

Ghana had a significantly smaller mean WC in its 80+ age category compared to its other age categories (Figure 8). Mexico and India also had significantly smaller mean WCs in their 80+ age categories compared to their 50-59 and 60-69 age categories, while South Africa's 80+ category was significantly smaller than the 60-69 category. No significant differences were found for China and Russian Federation.

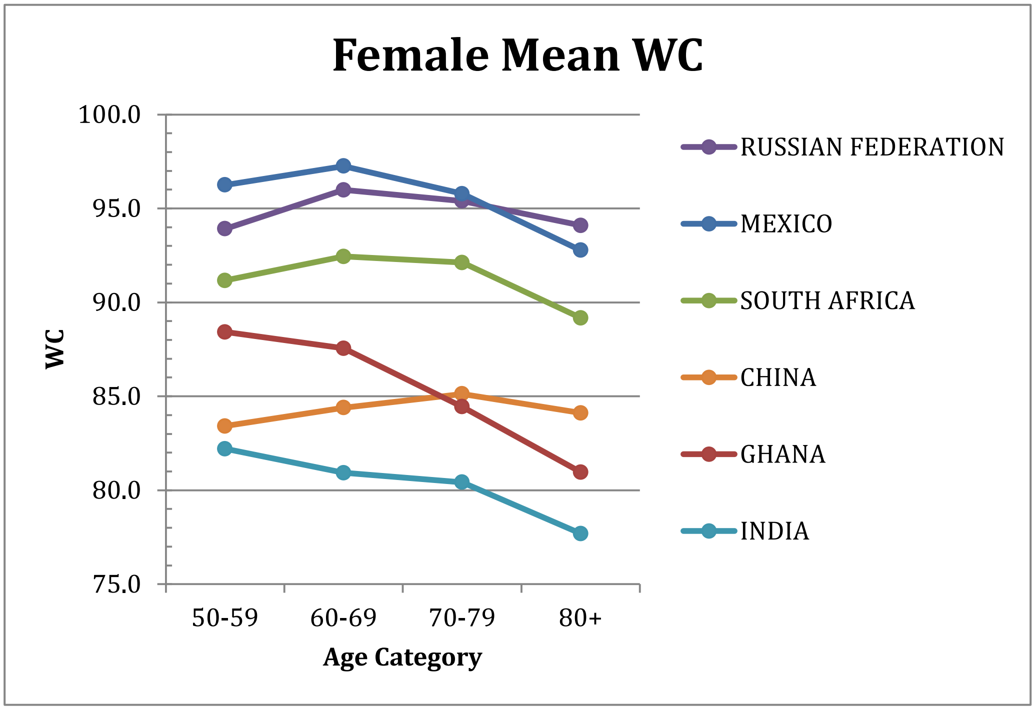

Figure 8: Female mean WC across age categories by country.

BAI

The mean BAI for Ghana's 80+ age category was significantly lower than the mean BAIs in the 50-59 and 60-69 age categories (Figure 9). Conversely, China's 80+ mean BAI was significantly greater than the mean BAIs of the 50-59 and 60-69 categories. No significant differences were found between the 80+ and the other three age categories in Mexico, Russian Federation, South Africa, and India.

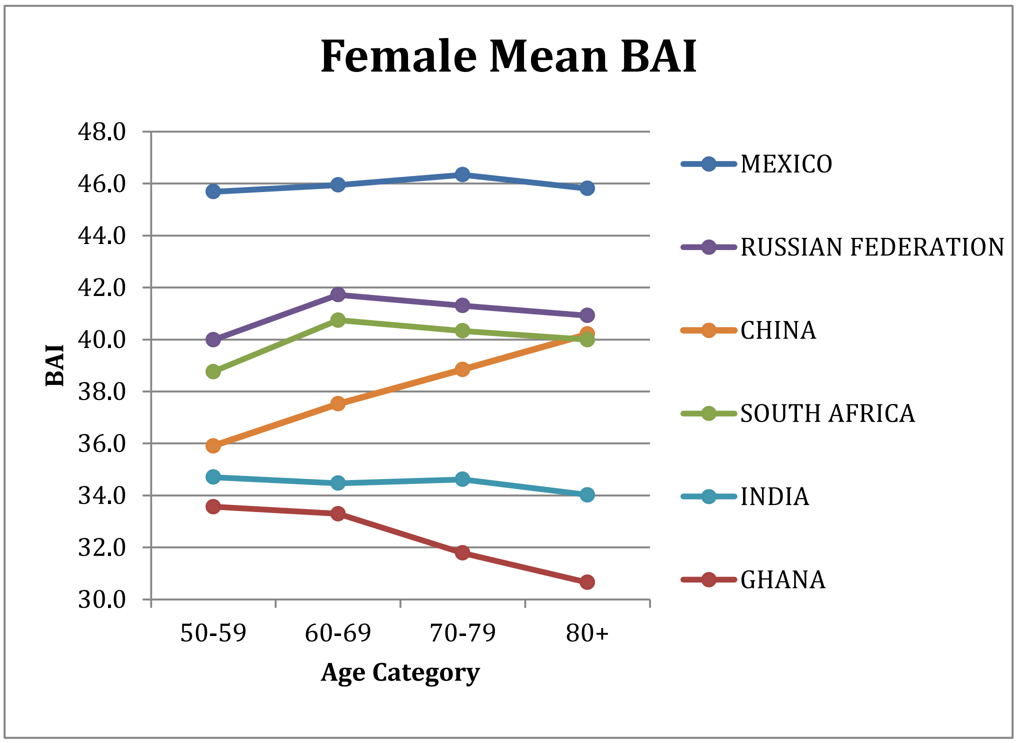

Figure 9: Female mean BAI across age categories by country.

Hypothesis Three – Examining Differences across Sex by Age Category and Country

BMI

Females had greater mean BMI values compared to males in all age categories and countries. Furthermore, China, Mexico, and South Africa had significant differences between male and female mean BMIs for all age categories except the 80+ age category. India and Ghana only had significant differences for the 50-59 and 60-69 age categories, while Russian Federation had significant differences between males and females in the 80+ age category.

WC

Mexico's 50-59, 60-69, and 70-79 age categories had significantly greater mean male WCs than mean female WCs. Conversely, South Africa's and Ghana's 50-59, 60-69, and 70-79 age categories; and Russia's 60-69 age category had significantly lower mean male WCs than mean female WCs. Sex differences in WC were non-significant in India and China.

BAI

For all countries and age categories, male and female mean BAIs significantly differed, wherein females had higher mean BAIs.

Hypothesis Four – Examining Differences across Country by Age Category and Sex

MALES:

BMI

For mean BMI, almost all countries were significantly different from each other in each age category (Figure 4). However, South Africa's and Mexico's 50-59, 60-69, and 70-79 age categories, and Russian Federation's and Mexico's 50-59, 60-69, 70-79, and 80+ age categories did not significantly differ from each other. South Africa and Russian Federation were not significantly different in the 70-79 and 80+ age categories. From largest to smallest male mean BMI, the countries generally followed the resulting order: South Africa, Russian Federation/Mexico, China, Ghana, India.

WC

Similar to BMI, almost all countries were significantly different from each other in each age category for WC (Figure 5). However, Ghana and India (all age categories), Ghana and China (50-59), Mexico and Russian Federation (80+), and South Africa and Russian Federation (80+) did not significantly differ from each other. From largest to smallest male mean WC, the countries resulted in the following order: Mexico, Russian Federation, South Africa, China, Ghana, India.

BAI

Most countries were significantly different from each other in each age category for BAI (Figure 6). However, Mexico and South Africa (all age categories), Ghana and India (all age categories), and China and Russian Federation (all age categories) were not significantly different from each other. Because of the similarities in BAI among these three pairs, the following order from largest to smallest male mean BAI resulted in three groupings: South Africa/Mexico, China/Russian Federation, Ghana/India.

FEMALES:

BMI

For female mean BMI, most countries were significantly different from each other in each age category (Figure 7). However, Mexico and Russian Federation (50-59, 60-69, 70-79), Ghana and China (60-69), and South Africa and Russian Federation (70-79, 80+) were not significantly different from each other. From largest to smallest female mean BMI, the resulting order of countries went as follows: South Africa, Russian Federation, Mexico, China/Ghana, India.

WC

Similarly, for female mean WC, all countries were significantly different from each other in each age category (Figure 8). However, Mexico and Russian Federation (all age categories), Ghana and India (80+), and Ghana and China (70-79, 80+) were not significantly different from each other. From largest to smallest female mean WC, the countries resulted in the following order: Russian Federation/Mexico, South Africa, Ghana/China, India.

BAI

Finally, for female mean BAI, the majority of countries significantly differed from one another across age categories (Figure 9). However, Ghana and India (50-59, 60-69), South Africa and Russian Federation (all age categories), China and South Africa (70-79, 80+), and China and Russian Federation (80+) did not significantly differ from each other. From largest to smallest female mean BAI, the countries resulted in the following order: Mexico, Russian Federation, South Africa/China, India, Ghana.

Hypothesis Five –BMI, WC, and BAI as Predictors of Hypertension

Across all countries, BMI was a significant predictor of being classified with hypertension after controlling for key variables. Specifically, as BMI increased, the likelihood of being classified with hypertension increased. As shown in Table 4, similar patterns occurred for WC and BAI but were slightly weaker.

	BMI		**WC**		**BAI**	
	Exp(B)	Sig.	Exp(B)	Sig.	Exp(B)	Sig.
Mexico	1.082	<0.001	1.029	<0.001	1.041	<0.001
Ghana	1.087	<0.001	1.023	<0.001	1.030	<0.001
South Africa	1.032	<0.001	1.008	<0.001	1.011	0.001
Russian Federation	1.104	<0.001	1.032	<0.001	1.038	<0.001
India	1.102	<0.001	1.035	<0.001	1.042	<0.001
China	1.151	<0.001	1.039	<0.001	1.039	<0.001

Table 4: Odds Ratios and Significance Values indicating the Likelihood of Hypertension Classification based on Body Composition Measures

Discussion

Hypothesis One

For most countries, the hypothesized lower prevalence of overweight and obese BMI categories as well as the increased risk WC category in the 80+ age category compared to younger age categories was confirmed in both males and females. However, increased risk prevalence based on WC was only lowest in 80+ females for half of the countries (Mexico, Ghana, and India). Interestingly, 80+ South African females had the highest prevalence of increased risk based on WC, even though they had the lowest mean WC for South African females.

Hypothesis Two

The hypothesized lower mean WC and BAI values in 80+ age categories compared to younger age categories for males and females in all countries was largely unsupported. However, the hypothesized lower mean BMI values in 80+ age categories was supported for females and somewhat supported for males. Mean BMI for females was significantly lower in the 80+ age category for all countries except India and South Africa where female 70-79 and 80+ populations were not considered significantly different. Mean BMI for males was lower in the 80+ age category for half of the countries (Mexico, Ghana, and China). WC tended to be similar across age categories for males while slightly lower in older age categories or similar across age categories for females. BAI tended to be similar across age categories or greater in older age categories for males, while it tended to be similar across age categories for females but demonstrated instances of both greater and lower means in the 80+ category compared to younger age categories.

Hypothesis Three

The hypothesized differences between males and females varied by body composition measure. Females had a significantly greater BMI than males for all age categories except 80+ for all countries (and except for 70-79 in Ghana). This convergence of 80+ male and female BMI on a common value in each country is particularly interesting.

Male and female mean WC also were not significantly different in the 80+ age category for all countries. Two of the six countries (India and China) did not have any significant differences between male and female mean WC in any of the four age categories. Varying cultural ideas of health and beauty in regards to body shape could have influenced this result. However, other influences such as diet and population density could have been involved as well.

Finally, male and female BAI were significantly different with females having higher BAIs in all age categories and countries. Interestingly, BAI was the only measure with significant sex differences in the 80+ category. While certain aspects of male and female body shapes in these populations may have been more similar in the 80+ category, hip circumference may have driven the greater number of sex differences observed in BAI. This is due to the relatively wider pelves in females for childbirth.

Hypothesis Four

In general, each body composition measure varied by country for each age category for both males and females, lending support to the fourth hypothesis. For each body composition measure for both males and females, there was at least one pair of countries that had similarities. For example, Ghana and India were not significantly different for male WC and BAI. Additionally, Ghana and India had the two lowest mean BMIs, WCs, and BAIs for each body composition measure for both males and females. For mean male BAI, the three groupings that occurred also makes BAI an interesting candidate for further research as a body composition measure in older adults.

Hypothesis Five

The hypothesis that WC and BAI are stronger than BMI as predictors of hypertension was unsupported by the data. While all three body composition measures had odds-ratios greater than one (denoting that as the value of each body composition measure increases, the likelihood of being classified with hypertension also increases), the odds-ratios for each body composition measure in each country were relatively similar to each other. Thus, BMI may indeed possess more utility in assessing obesity-related diseases than initially expected.

Still, the limitations of BMI in estimating abdominal adiposity remain apparent when comparing its patterns across age categories to those of WC and BAI. In terms of prevalence, overweight and obese BMI were less prevalent in older age categories with both males and females aged 80+ years generally having the lowest prevalence, suggesting that fewer adults in this age category are at risk for hypertension and other obesity-related diseases. However, only half of the countries had 80+ females as the lowest increased risk prevalence for WC, suggesting that more 80+ females have obesity-related health risks than BMI suggests. A side-by-side comparison of BMI and WC prevalence values for the female 80+ age category for each country further illustrates this discrepancy (see Table 5).

	% within Female 80+ Age Category	
	Combined Overweight + Obese BMI	Increased Risk WC
Mexico	60.0%	80.7%
Ghana	18.3%	51.1%
South Africa	59.9%	84.1%
Russian Federation	66.2%	75.5%
India	6.0%	34.5%
China	42.2%	68.8%

Table 5: BMI vs. WC prevalence values for 80+ females by country

Overweight and obese prevalence were added together to form a total percentage of 80+ females with obesity-related health risks by country as determined by BMI. Increased Risk WC prevalence was greater than overweight + obese BMI prevalence for all countries.

Additionally, in terms of continuous variables, BMI was lower in older age categories while WC and BAI tended to stay at similar levels across age categories. Once again, this suggests that BMI may underestimate older adults' obesity-related health risks. Furthermore, the larger BAI in the 80+ category for males and females in China as well as males in Russia further suggests that BAI could be a better candidate for measuring body composition and estimating obesity-related health risks in older adults. However, further research on BAI and its relations to cardiovascular and metabolic diseases must be conducted. Additionally, investigating why the three groupings of countries for BAI were established (Figure 6) could be interesting for future research.

Conclusion

Differences in body composition across countries, age categories, and sex were apparent to varying degrees in this set of populations. While the 80+ age categories for males and females in each country had the lowest values for each body composition measure (except male BAI) compared to the other age categories, the three body composition measures indicated different levels of obesity-related health risk for these populations. WC and BAI tended to estimate greater levels of health risk than BMI, especially for the 80+ age category. However, all three body composition measures were relatively similar predictors of hypertension in older adults. All three measures offer some degree of utility in estimating obesity-related health risks in large population studies, but which measure offers the most accurate and reliable results is yet to be conclusively determined. The results from this study tend to support the use of measures of abdominal adiposity (WC, BAI) over measures of general adiposity (BMI).

However, there were limitations to this study that are important to address. First, while the differences among body composition measures were outlined in many ways throughout this study, there was not a method included to determine any overlap between individuals classified as increased risk for WC and individuals classified as overweight or obese for BMI. When the two do not completely overlap (e.g., BMI classifies individuals with normal WC as obese instead of normal), there exist even greater differences among the body composition measures that are not made as clear in this study. Second, this study only used Wave 1 SAGE data collected from 2007-2010. Therefore, the patterns and trends observed across age categories are observations of different groups of people, not the same individuals aging over the years. Future studies could observe these same populations as the individuals age using similar methods when Wave 2 (2013-2014) and Wave 3 (2015-2016) data become available. With these data, even more direct and stronger relationships between body composition measures and aging in older adults could be revealed.

Appendix

ANTHROPOMETRIC MEASUREMENTS

I would now like to measure how tall you are. To measure your height I need you to please take off your shoes. Put your feet and heels close together, stand straight and look forward standing with your back, head and heels touching the wall. Look straight ahead.		
Q2506	*Measured height in centimetres*	☐☐☐.☐ centimetres *997 Refused* *998 Not able*
Now we want to measure your weight - could you please keep your shoes off and step on this scale. We will also measure your waist and hips using a tape measure.		
Q2507	*Measured weight In kilograms*	☐☐☐.☐ kilograms *997 Refused* *998 Not able*
Q2508	*Waist circumference* *INTERVIEWER: identify the top of the hip bone - and make sure the tape measure is parallel to the floor all the way around the body*	☐☐☐.☐ centimetres *997 Refused* *998 Not able*
Q2509	*Hip circumference* *INTERVIEWER: measure at the maximum circumference of the hips - and make sure the tape measure is parallel to the floor all the way around the body*	☐☐☐.☐ centimetres *997 Refused* *998 Not able*

Appendix Figure 1: Tables of height, weight, waist circumference, and hip circumference measurement techniques used by SAGE surveyors.

Blood Pressure

First I would like to measure your blood pressure and pulse rate. Stay seated, and once I put this on your wrist keep it steady and at the level of your heart. We will need to take the blood pressure reading three times. It will squeeze your wrist a bit, but won't hurt. Relax. *INTERVIEWER: respondent should remain seated. Demonstrate to the respondent how to hold their arm while the machine is measuring. Place the monitoring device on the wrist and have the respondent hold it at heart level against his/her chest. When the device is in the correct position and respondent is relaxed, press the button to start. Check to make sure it is working. Collect the blood pressure and pulse 3 times with one minute between each measurement. You do not need to remove the device between measurements.*			
Q2501	Time 1	Systolic ☐☐☐ Diastolic ☐☐☐	
Q2501a	Time 1	Pulse rate ☐☐☐	/ minute
INTERVIEWER: Ask the respondent to release the arm and relax. Wait for one minute before time 2. Do not ask the respondent questions. Use this time for quality control checks. Okay, now we can get your second measurement for your blood pressure.			
Q2502	Time 2	Systolic ☐☐☐ Diastolic ☐☐☐	
Q2502a	Time 2	Pulse rate ☐☐☐	/ minute
INTERVIEWER: Again, remind the respondent to relax. Meanwhile, when waiting to take the third measurement, you can locate and measure out a 4 metre length to prepare for the vision test and timed walk. Okay, now we can get your third measurement for your blood pressure.			
Q2503	Time 3	Systolic ☐☐☐ Diastolic ☐☐☐	
Q2503a	Time 3	Pulse rate ☐☐☐	/ minute

Appendix Figure 2: Tables of blood pressure measurement techniques used by SAGE surveyors.

TOBACCO AND OTHER SMOKING *(SEE APPENDIX A3000A)*

Q3001	Have you ever smoked tobacco or used smokeless tobacco?	1 YES 2 NO ....→	Q3007
Q3002	Do you currently use (smoke, sniff or chew) any tobacco products such as cigarettes, cigars, pipes, chewing tobacco or snuff?	1 YES, DAILY 2 YES, BUT NOT DAILY ....→ 3 NO, NOT AT ALL ....→	 Q3005 Q3005
Q3003	For how long have you been smoking or using tobacco daily? *INTERVIEWER: If less than one month – enter "00" for years and "00" for months.*	☐☐ YEARS ☐☐ MONTHS *-8 DON'T KNOW*	
Q3004	On average, how many of the following products do you smoke or use each day?	*Include number below:*	
	Q3004a. Manufactured cigarettes	☐☐	
	Q3004b. Hand-rolled cigarettes	☐☐	
	Q3004c. Pipefuls of tobacco	☐☐	
	Q3004d. Cigars, cheroots, cigarillos, bidis	☐☐	
	Q3004e. Smokeless tobacco	☐☐☐ GRAMS/DAY	
	Q3004f. Other, specify:	☐☐ . ...→	Q3007
Q3005	In the past, did you ever smoke tobacco or use smokeless tobacco daily?	1 Yes 2 No ....→	Q3007
Q3006	How old were you when you stopped smoking or using tobacco daily?	☐☐ YEARS OF AGE ....→ -8 *DON'T KNOW* ....→	Q3007 Q3006a
	Q3006a. How long ago did you stop smoking or using tobacco daily? *INTERVIEWER: If less than one month – enter "00" for months.*	☐☐ YEARS AGO ☐☐ MONTHS AGO -8 *DON'T KNOW*	

Appendix Figure 3: Tobacco and smoking survey questions.

ALCOHOL *(show Alcohol card to respondent - see Appendix A3000B)*

Q3007	Have you ever consumed a drink that contains alcohol (such as beer, wine, spirits, etc.)?	1 YES 2 NO, NEVER ....➔	Q3012
Q3008	Have you consumed alcohol in the last 30 days?	1 YES 2 NO ....➔	Q3010
Q3009	During the past 7 days, how many drinks of any alcoholic beverage did you have each day? *USE SHOWCARD Appendix A3000B.*	*INTERVIEWER: Want respondent to tell you the number of "standard" drinks. By standard drink - refer to Appendix. Include number below:*	
	Q3009a. Monday	☐☐	
	Q3009b. Tuesday	☐☐	
	Q3009c. Wednesday	☐☐	
	Q3009d. Thursday	☐☐	
	Q3009e. Friday	☐☐	
	Q3009f. Saturday	☐☐	
	Q3009g. Sunday	☐☐	
Q3010	In the last 12 months, how frequently [on how many days] on average have you had at least one alcoholic drink?	0 NO DAYS ....➔ 1 LESS THAN ONCE A MONTH 2 ONE TO THREE DAYS PER MONTH 3 ONE TO FOUR DAYS PER WEEK 4 FIVE OR MORE DAYS PER WEEK	Q3012
Q3011	In the last 12 months, on the days you drank alcoholic beverages, how many drinks did you have on average?	☐☐ DRINKS -8 *DON'T KNOW*	

Appendix Figure 4: Alcohol survey questions.

Q3016	Does your work involve vigorous-intensity activity that causes large increases in breathing or heart rate, [like heavy lifting, digging or chopping wood] for at least 10 minutes continuously? *INSERT EXAMPLES & USE SHOWCARD*	1 YES 2 NO .... →	Q3019
Q3017	In a typical week, on how many days do you do vigorous-intensity activities as part of your work?	☐ DAYS	
Q3018	How much time do you spend doing vigorous-intensity activities at work on a typical day?	☐☐:☐☐ HOURS:MINUTES	
Q3019	Does your work involve moderate-intensity activity that causes small increases in breathing or heart rate [such as brisk walking, carrying light loads, cleaning, cooking, or washing clothes] for at least 10 minutes continuously? *INSERT EXAMPLES & USE SHOWCARD*	1 YES 2 NO .... →	Q3022
Q3020	In a typical week, on how many days do you do moderate-intensity activities as part of your work?	☐ DAYS	
Q3021	How much time do you spend doing moderate-intensity activities at work on a typical day?	☐☐:☐☐ HOURS:MINUTES	
The next questions exclude the physical activities at work that you've already mentioned. Now I would like to ask you about the usual way you travel to and from places. For example, getting to work, to shopping, to the market, to place of worship. *[Insert other examples if needed]*			
Q3022	Do you walk or use a bicycle (pedal cycle) for at least 10 minutes continuously to get to and from places?	1 YES 2 NO .... →	Q3025
Q3023	In a typical week, on how many days do you walk or bicycle for at least 10 minutes continuously to get to and from places?	☐ DAYS	
Q3024	How much time would you spend walking or bicycling for travel on a typical day?	☐☐:☐☐ HOURS:MINUTES	
The next questions exclude the work and transport activities that you have already mentioned. Now I would like to ask you about sports, fitness, leisure and recreational activities [*insert relevant terms*].			
Q3025	Do you do any vigorous intensity sports, fitness or recreational (leisure) activities that cause large increases in breathing or heart rate [like running or football], for at least 10 minutes continuously? *INSERT EXAMPLES & USE SHOWCARD*	1 YES 2 NO .... →	Q3028
Q3026	In a typical week, on how many days do you do vigorous intensity sports, fitness or recreational (leisure) activities?	☐ DAYS	
Q3027	How much time do you spend doing vigorous intensity sports, fitness or recreational activities on a typical day?	☐☐:☐☐ HOURS:MINUTES	
Q3028	Do you do any moderate-intensity sports, fitness or recreational (leisure) activities that causes a small increase in breathing or heart rate [*such as brisk walking, cycling or swimming*] for at least 10 minutes at a time? *INSERT EXAMPLES & USE SHOWCARD*	1 YES 2 NO .... →	Q3031
Q3029	In a typical week, on how many days do you do moderate-intensity sports, fitness or recreational (leisure) activities?	☐ DAYS	
Q3030	How much time do you spend doing moderate intensity sports, fitness or recreational (leisure) activities on a typical day?	☐☐:☐☐ HOURS:MINUTES	
The following question is about sitting or reclining at work, at home, getting to and from places, or with friends including time spent [*sitting at a desk, sitting with friends, travelling in car, bus, train, reading, playing cards or watching television*], but do not include time spent sleeping. *INSERT EXAMPLES & USE SHOWCARD*			
Q3031	How much time do you usually spend sitting or reclining on a typical day?	☐☐:☐☐ HOURS:MINUTES	

Appendix Figure 5: Physical activity survey questions.

Bibliography

Ashwell M, Gunn P, and Gibson S. Waist-to-height ratio is a better screening tool than waist circumference and BMI for adult cardiometabolic risk factors: systematic review and meta-analysis. *Obesity Reviews* 2010; 13:275-286.

Chang H, Simonsick EM, Ferrucci L, and Cooper JA. Validation Study of the Body Adiposity Index as a Predictor of Percent Body Fat in Older Individuals: Findings From the BLSA. *Journals of Gerontology* 2013; 69.9: 1069-1075.

Figure 1. BMI vs. Body Fat. Reprinted from "The Y-Y paradox," by Chittaranjan SY and John SY, 2004, *The Lancet, 363(9403)*, p. 363. Copyright 2004 by Elsevier Ltd. Reprinted with permission from Elsevier.

Figure 2. SAGE Study Map. Reprinted from WHO, by WHO, 2012. Copyright 2012 by WHO.

Figure 3. Waist Circumference Measurement. Reprinted from "The Practical Guide: Identification, Evaluation, and Treatment of Overweight and Obesity in Adults" (NIH Publication No. 00-4084), by U. S. Department of Health and Human Services, National Institutes of Health, National Heart, Lung and Blood Institute, 2000, p. 9. Retrieved Feb. 16, 2015, from http://www.nhlbi.nih.gov/files/docs/guidelines/prctgd_c.pdf

Guasch-Ferré M et al. Waist-to-Height Ratio and Cardiovascular Risk Factors in Elderly Individuals at High Cardiovascular Risk. *PLoS ONE* 2012; 7.8.

IDF [International Diabetes Federation]. The IDF consensus worldwide definition of the metabolic syndrome. IDF Task Force on Epidemiology and Prevention. 2006. Brussels: International Diabetes Foundation.

Inelmen EM, Sergi G, Coin A, Miotto F, Peruzza S and Enzi G. Can obesity be a risk factor in elderly people? *Obesity Reviews* 2003; 4:147-155.

Janssen I, Heymsfield SB, Allison DB, Kotler DP and Ross R. Body mass index and waist circumference independently contribute to the prediction of nonabdominal, abdominal subcutaneous, and visceral fat. *The American Journal of Clinical Nutrition* 2002; 75:683-8.

Janssen I, Katzmarzyk PT and Ross R. Waist circumference and not body mass index explains obesity-related health risk. *The American Journal of Clinical Nutrition* 2004; 79:379-84.

Kowal P, Chatterji S, Naidoo N, Biritwun R, Fan W, Lopez Ridaura R, Maximova T, Arokiasamy P, Phaswana-Mufuya N, Williams S, Snodgrass JJ, Minicuci N, D'Este C, Peltzer K, Boerma JT and SAGE Collaborators. Data Resource

Profile: The World Health Organization Study on global AGEing and adult health (SAGE). *International Journal of Epidemiology* 2012; 41:1639-1649.

Larson MG. Descriptive statistics and graphical displays. *Circulation* 2006; 114:76–81.

Lee CMY, Huxley RR, Wildman RP and Woodward M. Indices of abdominal obesity are better discriminators of cardiovascular risk factors than BMI: a meta-analysis. *Journal of Clinical Epidemiology* 2008; 61:646-653.

Li W, Chen I, Chang Y, Loke S, Wang S and Hsiao K. Waist-to-height ratio, waist circumference, and body mass index as indices of cardiometabolic risk among 36,642 Taiwanese adults. *European Journal of Nutrition* 2013; 52:57-65.

Lloyd-Sherlock P, Beard J, Minicuci N, Ebrahim S, and Chatterji S. Hypertension among older adults in low- and middle-income countries: prevalence, awareness and control. *International Journal of Epidemiology* 2014; 43:116-28.

López, AA et al. Body Adiposity Index Utilization in a Spanish Mediterranean Population: Comparison with the Body Mass Index. *PLoS ONE* 2012; 7.4.

Malik, VS, Willett WC and Hu, FB. Global obesity: trends, risk factors and policy implications. *Nature Reviews Endocrinology* 2012; 1-15.

Moliner-Urdiales D, Artero EG, Sui X, España-Romero V, Lee DC and Blair SN. Body adiposity index and incident hypertension: The Aerobics Center Longitudinal Study. *Nutrition, Metabolism & Cardiovascular Diseases* 2014; 24:969-975.

Salihu HM, Bonnema SM and Alio AP. Obesity: What is an elderly population growing into? *Maturitas* 2009; 63:7-12.

Snijder MB, van Dam RM, Visser M and Seidell JC. What aspects of body fat are particularly hazardous and how do we measure them? *International Journal of Epidemiolog*y 2006; 35:83-92.

Stern D, Smith LP, Zhang B, Gordon-Larsen P and Popkin BM. Changes in waist circumference relative to body mass index in Chinese adults, 1993-2009. *International Journal of Obesity* 2014; 38:1503-1510.

Tatsumi Y et al. Effect of Age on the Association Between Waist-to-Height Ratio and Incidence of Cardiovascular Disease: The Suita Study. *Journal of Epidemiology* 2013; 23.5:351-359.

The World Bank. New Country Classifications. 2013. Available from: URL http://data.worldbank.org/news/new-country-classifications (accessed May 2015).

WHO [World Health Organization]. Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. *Lancet* 2004; 363:157-63.

WHO [World Health Organization]. Global status report on noncommunicable diseases 2014. 2014. Geneva: World Health Organization.

WHO [World Health Organization]. Obesity: Preventing and Managing the Global Epidemic. WHO Technical Report Series No. 894. 2000. Geneva: World Health Organization.

WHO [World Health Organization]. Waist Circumference and Waist-Hip Ratio: Report of a WHO Expert Consultation Geneva, 8-11, December 2008. 2011. Geneva: World Health Organization.