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A SYSTEMATIC APPROACH FOR THE CLASSIFICATION OF AGE-RELATED MUSCLE LOSS AND ELDERLY OBESITY USING FIELD-BASED TESTING METHODS AND ISOPERFORMANCE CURVES

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A SYSTEMATIC APPROACH FOR THE CLASSIFICATION OF AGE-RELATED MUSCLE LOSS AND ELDERLY OBESITY USING FIELD-BASED TESTING METHODS AND ISOPERFORMANCE CURVES

A DISSERTATION APPROVED FOR THE
DEPARTMENT OF HEALTH AND EXERCISE SCIENCE

BY

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ABSTRACT

The process of aging causes a wide variety of physiological changes that can manifest in the form of differing body composition phenotypes. A systematic approach to body composition classification and the subsequent selection of appropriate interventions is needed for community-based health care and fitness specialists. The primary purpose of this investigation was to determine body composition classification using field-based testing measurements in healthy elderly men and women. The use of isoperformance curves is presented as a method for this determination. Baseline values from 107 healthy Caucasian men and women over the age of 65 years old who participated in a separate longitudinal study were used for this investigation. Age, height, weight, body mass index (BMI), and handgrip strength were recorded on an individual basis. Relative skeletal muscle index (RSMI) and body fat percentage (FAT%) were determined by dual-energy X-ray absorptiometry (DXA) for each participant. Sarcopenia cut-off values for RSMI of 7.26 $kg \cdot m^{-2}$ for men and 5.45 $kg \cdot m^{-2}$ for women and elderly obesity cut-off values for FAT% of 27% for men and 38% for women were used. Individuals above the RSMI cut-off and below the FAT% cut-off were classified in the normal phenotype category, while individuals below the RSMI cut-off and above the FAT% cut-off were classified in the sarcopenic-obese phenotype category. The relationship between age and BMI, handgrip strength, RSMI, and FAT% was characterized using linear regression. Prevalence values for body composition phenotypes from actual DXA-based criteria and predicted RSMI and FAT% were evaluated. Using the DXA criterion values for RSMI and FAT%, 34 individuals (32% of the sample) were classified as normal, 50 individuals (47% of the sample) were classified as obese, 10 individuals (9% of the sample) were classified as sarcopenic, and 13 individuals were classified as sarcopenic obese. Prediction equations for RSMI and FAT% from BMI and handgrip strength values were developed using multiple regression analysis. The prediction equations were validated using double cross-validation. The final regression equation developed to predict FAT% from BMI and handgrip strength resulted in a strong relationship (adjusted R^2=0.741) to DXA values with a low standard error of the estimate (SEE=3.9937%). The final regression equation developed to predict RSMI from the field-based testing measures also resulted in a strong relationship (adjusted R^2=0.841) to DXA values with a low standard error of the estimate (SEE=0.5437 $\text{kg}\cdot\text{m}^{-2}$). Using the prediction values for FAT% and RSMI, 30 individuals (28% of the sample) were classified as normal, 58 individuals (54% of the sample) were classified as obese, 17 individuals (16% of the sample) were classified as sarcopenic, and 2 individuals (2% of the sample) were classified as sarcopenic obese. Subsequently, isoperformance curves were used to aid in the classification and evaluation of sarcopenia, obesity, and sarcopenic obesity in elderly individuals by graphically representing the relationship between BMI and handgrip strength with the aforementioned clinical phenotype classification criteria. The final goal of this investigation was to produce easily understood charts that can be used by personal trainers, nutrition specialists, and/or health professionals. The charts could be used in the classification of individuals into these phenotype categories in an inexpensive and non-invasive manner. Future research should be undertaken that enhances the current findings by increasing the sample size and developing tailored interventions for each body composition category.

CHAPTER I

INTRODUCTION

Aging in humans is the accumulation of multifaceted physiological changes over time which influence body composition. After progressively increasing throughout the first four decades of life, skeletal muscle mass in humans begins to slowly decrease and is linked with a concomitant increase in body fat percentage (29). Baumgartner termed these changes as “syndromes of disordered body composition,” or body composition phenotypes, and noted that the association between them varied with age (39). The initial hypothesis for the development of these body composition phenotypes with aging involved a decrease in total energy expenditure generally explained by a combination of the attenuation of physical activity and a reduction in basal metabolic rate (57). Additional factors related to the aging process, including hormonal changes, inflammation, malnutrition, and altered muscle function, have since been investigated (29). Despite lacking a consistent definition and etiology for the age-related variations in body composition, it is estimated that the loss of muscle mass in the elderly resulted in health care costs of over $18.4 billion in the United States (32) and that the number of people over the age of 60 years old affected worldwide could increase to 1.2 billion in the next two decades (19). In response to the ongoing research and potential economic impact involving these multifactorial syndromes, a number of international working groups have been formed to critically define the phenotypes and to develop diagnostic criteria for clinical use (19, 27). While these working groups are serving the clinical and research organizations, a systematic approach to the classification of body composition phenotypes and subsequent selection of appropriate interventions is needed for community-based health care and fitness specialists.

Body composition assessment in humans involves the differentiation between components of the total body mass or area with similar physical properties. The two-component model is divided between fat mass and fat-free mass, whereas the tissue-level three-component model also determines fat mass but further distinguishes fat-free mass into lean mass and bone mineral content (82). During body composition validation studies, these models are compared to four-component models which are generally considered more complete and often utilize multiple assessment techniques (82). Numerous methods of body composition assessment are available and specific considerations are needed when applying these techniques in the elderly population (58). Dual-energy X-ray absorptiometry (DXA) is a technique that is commonly utilized to determine lean mass and body fat percentage in the elderly (80). DXA measures the relative attenuation of X-rays of two differing energy levels with minimal radiation exposure and was initially used to characterize bone mineral content (58). Subsequent research examining the absorbed and reflected energy in the areas not taken up by bone mineral content has allowed for the determination of whole body and regional fat and lean mass (104). Benefits of DXA include high levels of precision with minimal bias (74) and extensive data feedback, however the instrumentation can be expensive, requires trained operators, and the hydration status of the individual being tested may affect body composition estimates (58). Nonetheless, DXA has been reported to provide greater reliability than other methods of body composition assessment (88), including bioelectrical impedance analysis

(BIA), and tracks changes in fat and lean mass better than BIA, as well as air displacement plethysmography, when compared to a four-component model (96).

Two specific variables from DXA are of interest when examining the phenotypes of body composition in the elderly. These variables are body fat percentage (FAT%) and relative skeletal muscle index (RSMI) and each examines a specific component of body composition that affects humans during aging. Fat mass from DXA is calculated as bone-free area with an estimated ratio of the high and low energy X-rays comparable to a phantom equivalent of 100% fat mass (103). FAT% is determined as the ratio of fat mass to total body mass. Fat mass values derived from DXA, specifically Lunar systems, have been shown to be nearly equivalent to those obtained from gold standard reference methods, including magnetic resonance imaging, computed tomography and four-component models (91, 95, 103). Lean mass from DXA is calculated as bone-free area with an estimated ratio of the high and low energy X-rays comparable to a phantom equivalent of 100% lean mass (103). A higher ratio of low-energy to high-energy transmission is indicative of lean mass, whereas a lower ratio is indicative of fat mass (103). Appendicular lean mass is the sum of both segmental arm and leg lean mass estimations, which has shown to be accurately measured by DXA when compared to in vivo neutron activation and computed tomography (79, 103). The sum of these compartments accounts for more than 75% of total body skeletal muscle mass and may represent the ability to be physically active (79). RSMI accounts for individual allometric variations and is calculated by dividing appendicular lean mass by height squared (9). The determination of RSMI and FAT% from DXA in the elderly provides for the organization of individuals into classifications of normal body composition, sarcopenia, obesity, and sarcopenic obesity.

The term sarcopenia, originally proposed by Rosenberg in 1989 (87), is derived from the Greek root terms *sarx*, meaning flesh, and *penia*, meaning loss, which together have been defined as the age-related loss of muscle mass (52). While the pathophysiology of sarcopenia is still being researched, one of the primary mechanisms is the loss of motor unit activity via nerve degradation (106). This degradation results in the loss of the type II fast twitch muscle fibers and the associated muscle power needed to adequately perform activities of daily living, as well as an increase in the overall percentage of type I slow twitch muscle fibers (106). Following mid-life in humans (40 to 50 years old), conservative estimates between two and six percent per decade for the loss of fat-free mass have been reported (17, 23). Sarcopenia has been hypothesized to be a normal part of physiological aging and can be differentiated from disease-related changes associated with pathological or secondary aging, termed cachexia (52, 106). A number of different methods exist to classify individuals as being sarcopenic. One of the most commonly utilized standards was developed by Baumgartner and colleagues from DXA using a Lunar system (9). Baumgartner et al. (9) described sarcopenia as two standard deviations below the mean RSMI of a sample of young adults, which corresponded to 7.26 $kg \cdot m^{-2}$ in men and 5.45 $kg \cdot m^{-2}$ in women. The prevalence of sarcopenia using this method in individuals over the age of 65 years old has been estimated to be greater than 20% and increases to 30% in women and greater than 50% in men over the age of 80 years old (76). Classification of sarcopenia in the elderly has been related to physical disability, functional impairment, muscle strength, lower extremity function, and mortality (7, 9, 59, 113). Longitudinal studies examining the effects of sarcopenia have shown greater associations with disability than cross-sectional studies (87). Consequently, Goodpaster et al. (71) noted that muscle strength decreases at a greater rate than muscle size and that the relationship between the two variables, defined as muscle quality, has been shown to be an effective tool in the estimation of mortality risk (59).

The prevalence of elderly obesity is characterized by an estimated 7.5% increase in fat mass between the ages of 60 and 70 years old (17), while the increase in body fat tends to reverse after this period in the lifespan (14, 66). An increase in FAT% with age is partially explained by decreased lean mass (89), but contributions by increased intramuscular fat, energy balance, insulin resistance, and many of the same factors related to sarcopenia may also be relevant (80). Approximately 30% of men and women over the age of 60 years old are considered obese (92). Baumgartner et al. (9) defined elderly obesity as FAT% greater than the sex-specific median values for a large cohort of men and women over the age of 60 years old, which corresponded to 27% in men and 38% in women. Similarly, the American College of Sports Medicine (18) has published standards for the same age range of approximately 28% in men and 36% in women for body composition to be considered poor (20th percentile). Classification of obesity in the elderly has been related to functional limitations, lifestyle factors, and insulin resistance, as well as muscle quality (20, 38, 44, 49). Furthermore, obesity has shown to be a better predictor of physical performance than muscle mass in this population (49). Additionally, Bouchard et al.

(112) reported obesity might be more closely associated with physical capacity than sarcopenia.

The combination of these two body composition phenotypes in the elderly has been termed sarcopenic obesity (39). Elderly obesity and sarcopenia share many of the previously discussed pathophysiological mechanisms. The prevalence of sarcopenic obesity in men and women greater than 65 years old has been estimated to range between 9% and 12% (29). This evaluation may be underestimated due to the possibility of DXA misinterpreting fat mass found within muscle as lean mass in obese individuals (70, 80). The combination of low muscle mass and intramuscular fat infiltration has shown to be positively associated with lower extremity function (21). Sarcopenic obesity has been related to decreased mobility and increased disability with regard to activities of daily living (29, 45). Baumgartner et al. showed that sarcopenic obesity, more than sarcopenia or obesity alone, was associated with physical disability, balance abnormalities, gait abnormalities, and falls in the previous year in a group of elderly men and women (39).

The determination of FAT% and RSMI from DXA provides a method for classification of body composition phenotypes in the elderly, but the cost and availability of DXA may be prohibitive in community-based health care and fitness center settings. As a result a number of prediction equations using field-based testing measurements have been formulated (1, 76, 77, 88). Baumgartner et al. (9) published a prediction equation for appendicular skeletal muscle from DXA using weight, height, hip circumference, grip strength, and age. Sex was found to be a significant predictor of body fat percentage and along with waist circumference, hip circumference, triceps skinfold was used to develop an additional DXA FAT% prediction equation in the elderly (9). Levitt et al. (77) used various equations structured around BMI, sex, and age as predictors of FAT% as estimated from underwater weighing. More recently, Sanada et al. developed separate skeletal muscle index (SMI) equations for men and women. The SMI prediction equation in men used BMI, waist circumference, and age, while in women the prediction equation used BMI, grip strength, and waist circumference. Hence, BMI, handgrip strength and sex have all previously been used as predictors in the estimation of body composition.

The adjustment of body weight by an individual's stature, as an index of body shape, was first proposed by Adolphe Quetelet in 1832 (24). The Quetelet Index, which has since become known as body mass index (BMI), is calculated as weight divided by height squared (10). BMI, better than or equivalent to various other anthropometric indices, has been shown to be a predictor of adiposity in humans (43, 63). While BMI is influenced by a number of factors, including age, sex, ethnicity, diet, and physical activity, it is highly correlated with skinfold thickness as well as body fat percentage from DXA and four-component models (2, 10, 36, 94). Results from a longitudinal study by Guo et al. (83) showed that BMI increased 0.11 $kg \cdot m^{-2}$ per year for men and 0.22 $kg \cdot m^{-2}$ per year for women between the ages of 40 and 66 years, while BMI tends to decrease in individuals between 65 and 85 years old (14, 98). BMI in the elderly has been related to physical function, frailty, and mortality (15, 37, 84). With regard to mortality, BMI has shown a U-shaped relationship with relatively healthy individuals falling between 20 and 30 $kg \cdot m^{-2}$ (14, 15). When used as a predictor of FAT%, BMI has a linear relationship for individuals below 50 $kg \cdot m^{-2}$

(77). While BMI is commonly used as a measure of adiposity, Heymsfield et al. (73) reported that both fat mass and lean mass were significant determinants of BMI in adults between the ages of 33 and 45 years old. Additionally, variations in BMI have shown to be related to changes in fat and lean mass in elderly women (34). Therefore, BMI may be an adequate predictor of both muscle and adipose tissue in the elderly.

As previously discussed, muscle strength decreases at a greater rate than muscle mass during the process of aging in humans (59, 71). Additionally, the loss of muscle strength accelerates with advanced aging (71, 75). A common measurement of strength in the elderly is handgrip strength (47), which decreases with advanced aging (46). Handgrip strength has been shown to decline at a faster rate after the age of 30 years old in men and 50 years old in women (113). The relationship between sarcopenia and grip strength has long been noted. In 1931, Critchley's manuscript, *The neurology of old age*, was published (101) and in it he stated that "the commonest site for a strictly localized atrophy is in the hands." Subsequently, handgrip strength has been shown to be related to disability, compromised health, and prolonged hospitalization (22, 48, 51). With respect to mortality in the elderly, grip strength and leg strength have shown to provide similar predictive ability (59). Furthermore, some researchers have indicated that grip strength may a better indicator of survival than muscle size (52). Handgrip strength has been shown to be significantly correlated with muscle as well as used as a predictor, with other anthropometric measures, of appendicular lean mass (1, 9). Woo et al. (37) reported handgrip strength decreases with increased fat mass and decreased lean mass as determined by DXA in elderly men and women. Fat infiltration in the muscle, termed myosteatosis, has been shown to decrease strength (21, 57). Subsequently, handgrip strength and BMI have been used in conjunction to assess the impact of body composition phenotypes in the elderly (29, 84). The prevalence of sarcopenic obesity, using handgrip and BMI as indicators, falls between 4 and 9% in individuals over the age 65 years old (29). Furthermore, sarcopenic obese individuals present lower grip strength values relative to body weight compared to those in the other body composition phenotype classifications (39). The relationship between handgrip strength and both lean and fat mass may be exploited in an effort to examined phenotypes of body composition in the elderly.

Elderly men and women differ with regard to changes in body composition over the lifespan as well as with the field-based testing measurements associated with the aforementioned phenotypes. FAT% is lower and lean mass is higher in men than women between the ages of 70 and 80 years old, while BMI is similar (13). Grip strength is higher in elderly men than elderly women, but has only shown to be a significant predictor of appendicular lean mass in men, while BMI was found to be a significant predictor for both men and women (13, 76). Obesity prevalence in men and women over the age of 60 years old is similar at around 70% (92). Sarcopenia prevalence in men and women over the age of 60 years old has been shown to be similar (20-30%), but increases to a greater degree in men than women over the age of 80 years old (76). Therefore, sex may be related to the phenotypes of body composition in the elderly.

Isoperformance curves are lines determined by two or more variables that can be used to demarcate between varying levels of performance (55, 68). The use of isoperformance curves has been previously explored in applied psychology and human factors engineering to aid in the process of balancing variables in order to achieve a minimum desirable level of performance as opposed to performance maximization (28, 30, 105). While performance maximization is oftentimes the desired result in exercise science and athletics settings, de Weck and Jones (30) outlined the use of batting ability (runs batted in; RBI) and pitching ability (earned run average; ERA) to estimate a minimum performance level with regards to the final league standings (win/loss percentage) during a Major League Baseball season. Subsequently, Morton (68) proposed the use of isoperformance curves with the existing critical velocity concept during team selection in rowing. This methodology was further expanded by using the aerobic and anaerobic variables provided by the critical velocity test to determine physiological profiles and training needs in athletes, as well as differentiate between individuals using the Army Physical Fitness Test 2-mile run scoring system as a basis for performance (31, 70).

The classification of body composition phenotypes in the elderly provides a unique opportunity to apply the isoperformance methodology. Prediction equations for RSMI and FAT% from field-based testing measurements, such as BMI and handgrip strength, along with pre-defined cut-off values may be used to differentiate individuals into classifications of normal body composition, sarcopenic, obese, and sarcopenic obese. BMI, as an indicator of adiposity, may be viewed as a general marker of body weight and shape, while handgrip strength, as an indicator of lean mass, may be viewed as a general marker of muscle function and overall physical ability. Furthermore, evaluation of these field-based testing measurements on an individual basis may allow for the determination of appropriate interventions for elderly men and women in each of these body composition phenotype classifications.

Purpose

1. The primary purpose of this investigation was to propose a systematic approach to body composition classification using field-based testing measurements in healthy elderly men and women.
2. An additional purpose was to devise a prediction equation for relative skeletal muscle index (RSMI) from body mass index (BMI) and handgrip strength values using multiple regression analysis.
3. An additional purpose was to devise a prediction equation for body fat percentage (FAT%) from body mass index (BMI) and handgrip strength values using multiple regression analysis.
4. An additional purpose was to develop isoperformance curves to aid in the classification and evaluation of sarcopenia, obesity, and sarcopenic obesity in elderly individuals.

Hypotheses

1. It was hypothesized that healthy elderly men and women could be systematically classified with regard to body composition using values from field-based testing measurements.
2. It was hypothesized that BMI and handgrip strength could be used to formulate a cross-validated prediction equation for RSMI.

3. It was hypothesized that BMI and handgrip strength could be used to formulate a cross-validated prediction equation for FAT%.
4. It was hypothesized that isoperformance curves could be effectively used to classify and evaluate sarcopenia, obesity, and sarcopenic obesity in elderly individuals.

Operational Definition of Terms

Appendicular lean mass – the sum of arm lean mass and leg lean mass

Relative skeletal muscle index – the ratio of appendicular lean mass to height squared

Constant error – average difference between the measured and predicted values for the cross-validation group; bias (82)

Total error – average deviation of individual scores of the cross-validation sample from the line of identity (82)

Standard error of estimate – measure of prediction error; quantifies the average deviation of individual data points around the line of best fit (82)

Isoperformance curves – lines determined by two or more variables that can be used to demarcate between varying levels of performance

Dual-energy x-ray absorptiometry – method used in clinical and research settings to estimate body composition from X-ray attenuation (82)

Abbreviations

ALM – Appendicular lean mass (kg)

BM – Body mass (kg)

BMI – Body mass index ($kg \cdot m^{-2}$)

CE – Constant error/mean difference

DXA – Dual-energy X-ray absorptiometry

FFM – Fat-free mass (kg)

FM – Fat mass (kg)

HT – Height (cm)

r – Pearson product moment correlation coefficient

R^2 – Coefficient of determination

RSMI – Relative skeletal muscle index ($kg \cdot m^{-2}$)

SEE – Standard error of estimate

TE – Total error

LOA – Limits of agreement

Delimitations

Baseline values from 107 healthy Caucasian men and women over the age of 65 years old who participated in a separate longitudinal study were used for this investigation. Participants were volunteers who completed a general health history questionnaire and a written informed consent prior to testing. All participants were ambulatory and a self-reported BMI between 20 and 30 $kg \cdot m^2$. Individuals were excluded from participation if they had any major health limitations, including recent major surgery (within four weeks), current active malignant disease, immunodeficiency disorder, history of diabetes, kidney disease, partial or full artificial limb, uncontrollable hypertension, and recent myocardial infarction (within three months).

Assumptions

Theoretical Assumptions

1. The health history document was completed accurately

2. All participants gave maximal effort during the handgrip strength testing
3. Equipment performed properly

Statistical Assumptions

1. Normality of variables and residuals from regression analysis
2. Lack of multicollinearity
3. Homoscedasticity of residuals from regression analysis
4. Reliability of testing measures
5. Specification error with regard to number of relevant predictors
6. Minimal inclusion of outliers

<u>Limitations</u>

1. Participants were recruited from Norman, Oklahoma and surrounding areas and may not represent all men and women over the age of 65 years old.
2. Participants were recruited on a volunteer basis, so the sample is not a true random selection from the population.
3. Due to the healthy nature of the sample, the number of sarcopenic or obese individuals may be minimal.

CHAPTER II

REVIEW OF LITERATURE

The importance of the classification of sarcopenia

Baumgartner, Koehler, Gallagher, Romero, Heymsfield, Ross, Garry, and Lindeman, 1998 (9)

Cut-off values for sarcopenia; relationship between muscle loss and physical disability

The purpose of this study was to outline a method to classify sarcopenia using relative skeletal muscle mass and to examine the relationship between sarcopenia and health outcomes. Subject data was taken from 883 elderly men and women (mean age of 74 years old) that participated in the New Mexico Elder Health Survey. Self-reported disability was determined from the Activities of Daily Living and Instrumental Actvities of Daily Living (IADL) scales. Balance and gait abnormalities as well as frequency of falls and use of assistive device to walk were also recorded. Weight, height, hip circumference, grip strength, and age were used to determine a prediction equation for appendicular skeletal muscle (ASM) from DXA reference data (Aging Process Study; Rosetta Study) using a Lunar system (R^2=0.91, SEE=1.58kg). Waist circumference, hip circumference, triceps skinfold, and sex were used to determine a prediction equation for body fat percentage using the same reference data (R^2=0.79, SEE=3.94%). Relative skeletal muscle mass index (RSMI) was calculated as the predicted ASM divided by height squared. Sarcopenia cut-off points were determined as two standard deviations less than the young adult mean for RSMI from reference data (Rosetta Study, 18-40 years old). These values were reported to be 5.45 $kg \cdot m^{-2}$

for women and 7.26 kg·m^{-2} for men. According to these cut-off points, 13-24% of elderly men and women under 70 years of age were classified as sarcopenic and for those over 80 years old the prevalence was greater than 50%. In men, sarcopenia was significantly associated with having 3 or greater self-reported disabilities, greater than 1 balance abnormality, use of a cane/walker, and having fallen during the past year. In women, sarcopenia was significantly associated with having 3 or greater self-reported disabilities. The results of this study were the establishment of a method for determining sarcopenia cut-off points and evaluating the prevalence of sarcopenia in elderly men and women. Additionally, sarcopenia classification was shown to increase the odds of physical disability.

Iannuzzi-Sucich, Prestwood, and Kenny, 2002 (76)

Prevalence of sarcopenia; BMI as a predictor of skeletal muscle mass

The purpose of this study was to evaluate the prevalence of sarcopenia in healthy, elderly men and women and to determine potential predictor variables in this group. Subject data was taken from four separate cross-sectional studies totaling 337 men and women in the United States over the age of 65 years old. Relative skeletal muscle index was calculated from appendicular skeletal muscle mass (ASM) using DXA (Lunar) and cut-off points as established by Baumgartner et al were used. Physical activity, strength, performance, and quality of life measures were collected. Additionally, vitamin D and sex hormone concentrations were measured from blood and urine samples. Sarcopenia prevalence in the examined cohort was 22.6% and 26.8% for women and men, respectively. In those individuals over 80 years old, the prevalence rates increased to 31% in women and 52.9% in men. Using linear regression analysis, BMI was a significant predictor of ASM in both men and women, accounting for 50.1% and 47.9% of the variance, respectively. For men, mean leg extension strength, mean leg extension power, and testosterone levels were also significant predictors of ASM, accounting for 10.3%, 4.1%, and 2.6% of the variance, respectively. The results of this study confirmed previous sarcopenia prevalence rates of greater than 20% in healthy, independently-living, elderly individuals. Furthermore, BMI in both men and women and strength in men only were shown to be significant predictors of ASM.

Newman, Kupelian, Visser, Simonsick, Goodpaster, Nevitt, Kritchevsky, Tylavsky, Rubin, and Harris, 2003 (70)

Sarcopenia classifications from DXA and the consideration of fat mass

The purpose of this study was to assess sarcopenia classifications as a function of appendicular lean mass (ALM) relative to height squared or adjusted for height and fat mass. Additionally, the relationship between sarcopenia and lower extremity function was examined. Subject data was taken from 3,075 well-functioning elderly men and women, 70 to 79 years old, living in the United States who participated in the Health Aging and Body Composition (Health ABC) Study. Body composition measurements were determined from DXA using a Hologic system. Relative lean mass was calculated as ALM divided by height squared and sarcopenia cut-off points were determined as the lowest 20% of the study distribution (5.67 $kg \cdot ht^{-2}$ for women and 7.23 $kg \cdot ht^{-2}$ for men). The 20th percentile of residuals using sex-specific linear regression from the relationship between ALM on height and fat mass were used as an alternative method of defining sarcopenic individuals (-2.29 for men and -1.73 for women). Lower extremity function was determined from chair stand, gait speed, and standing balance using a total score of 12 with impairment designation as a score of less than 10. The two methods of sarcopenia classification were highly correlated (men, r=0.88; women, r=0.71). Relative lean mass was correlated with BMI (men, r=0.76; women, r=0.85) and when compared to the residual cut-off points identified fewer individuals as sarcopenic. The relative lean mass method did not classify any of the obese individuals (BMI ≥ 30) as sarcopenic, whereas the residual method identified 11.5% of men and 21.0% as sarcopenic. In men, individuals classified as sarcopenic by both the ALM and residual methods were more likely to be associated with functional limitations. In women, the residual method showed greater odds for functional limitations in sarcopenic individuals, while the ALM method did not. The results of this study showed that fat mass may need to be considered when determining sarcopenia in obese individuals. Furthermore, sarcopenia is associated with decreased lower extremity function in healthy, elderly individuals.

Zoico, Di Francesco, Guralnik, Mazzali, Bortolani, Guariento, Sergi, Bosello, and Zamboni, 2004 (113)

SMI as an index of sarcopenia as well as functional impairment and disability

The purpose of this study was to compare different indices of body composition and their relationship with leg strength and functional limitations in healthy elderly women. An elderly group of 167 women aged 67 to 78 years and a young group of

120 women aged 20 to 50 years (for reference data) living in Italy were recruited to participate in this study. Appendicular skeletal muscle mass was determined from DXA using a Hologic system. ASM relative to height squared was calculated for comparison with other indices of muscle mass and body mass index. Total body skeletal muscle mass was calculated from a prediction equation developed by Kim et al. (3) incorporating ASM, sex, and age. Relative muscle mass was then determined as predicted total body skeletal muscle mass divided by height squared. The total body skeletal muscle mass was included in the skeletal muscle index (SMI) prediction developed by Janssen et al. which results in percentage skeletal muscle mass. Leg strength was measured during isometric contraction of the knee extensors and recorded as the mean peak torque during three trials. Functional limitations were determined using a combination of self-reported activities of daily living scales. Twenty-seven percent of the elderly women were considered sarcopenic, 27% were obese, and 12% were both sarcopenic and obese. Functional limitations were more likely to be present in women in the obese category according to BMI (>30), the highest quintile for body fat percentage, the lowest quintile for relative muscle mass, and those classified as Class II sarcopenic using SMI. Leg strength was significantly lower in the lowest relative muscle mass quintile compared to the highest quintile. The normal category showed significantly greater leg strength than the sarcopenic and sarcopenic obese categories. The results of this study showed differing outcomes between body composition indices. Body fat and BMI showed the greatest association with functional limitations.

Janssen, 2006 (87)

Sarcopenia as an indicator of disability in cross-sectional and longitudinal studies

The purpose of this study was to compare the risk of physical disability in a cross-sectional versus longitudinal context. The study data was from 5,317 healthy men and women in the United States over the age of 65 years old from the United States who participated in the Cardiovascular Health Study. Prevalent disability from a standardized questionnaire reflecting activities of daily living was assessed at baseline and, annually, for a follow-up period of eight years. Bioelectrical impedance analysis was used to estimate whole-body muscle mass and skeletal muscle index was calculated as whole body muscle mass divided by height squared. Cut-off points were determined by sex-specific quartiles of the skeletal muscle index from the study sample and by previously established values for normal, moderate, and severe sarcopenia. Accordingly, 70.7% of men and 41.9% of women were in the moderate sarcopenia group, while 17.1% of men and 10.7% of women were in the severe sarcopenia group. At baseline, the disability odds ratio for sarcopenia was 1.79 compared to 1.08 for moderate sarcopenia. When examined in the context of longitudinal data, the disability hazard ratio for severe sarcopenia was lower at 1.27, while the hazard ratio for moderate sarcopenia was similar at 1.07. When the group was split by sex for both cross-sectional and longitudinal data, severe sarcopenia was an indicator of disability risk in women, but not men. The results of this study showed that severe sarcopenia was significantly associated with disability risk in cross-sectional data and, to a greater degree, in longitudinal data.

Newman, Kupelian, Visser, Simonsick, Goodpaster, Kritchevsky, Tylavsky, Rubin, and Harris, 2006 (59)

Muscle quality rather than muscle strength should be considered when estimating mortality risk; handgrip and leg strength are both predictors of mortality

The purpose of this study was to examine the relationship between body composition as measured by DXA and computed tomography (CT) with strength and mortality in elderly men and women. Subject data was taken from 2,292 men and women aged 70 to 79 years living in the United States who participated in the Health, Aging, and Body Composition (Health ABC) Study. Mortality was determined during an average follow-up period of 10 years. Lean muscle mass was determined by DXA using a Hologic system and by CT scan. Body mass index was also calculated. Strength measures included isokinetic knee extension and isometric handgrip. Muscle quality was calculated as the ratio of muscle size to muscle strength. During the follow-up period, 286 deaths occurred, accounting for 33.1 per 1000 person-years in men and 18.1 per 1000 person-years in women. Leg strength and handgrip strength were both strongly associated with mortality in this cohort. This association was similar for both the DXA and CT measurements. Conversely, only leg muscle size from the CT scan was shown to be related to mortality. Muscle quality for both leg and handgrip using DXA and CT measurements were also strongly associated with mortality. The results of this study show that muscle strength may be a more useful tool than muscle size when determining mortality risk. Muscle quality is another method examined in this investigation that has merit when assessing mortality. Lastly, grip strength and leg strength provide similar measures when attempting to predict mortality.

Goodpaster, Park, Harris, Kritchevsky, Nevitt, Schwartz, Simonsick, Tylavsky, Visser, and Newman, 2006 (71)

Muscle strength declines faster than muscle mass in the elderly; importance of muscle quality

The purpose this study was to compare changes in muscle strength with muscle mass and body weight in the elderly. Subject data was taken from 3,075 men and women aged 70 to 79 years living in the United States who participated in the Health, Aging, and Body Composition (Health ABC) Study. Changes in strength and body composition were determined during a follow-up period of three years. Total body and leg lean muscle mass was determined by DXA using a Hologic system and thigh muscle cross-sectional areas was determined by computed tomography (CT) scan. Body mass index was also calculated. Leg strength was measured by isokinetic knee extension using a Kin-Com dynamometer. Men showed a greater decline in leg torque and leg lean mass than women over the three-year follow-up. The average decline in leg strength was approximately 3% compared to an approximate loss of 1% in leg lean mass. Interestingly, body mass stability or gain over the course of three years did not translate to strength stability or gain. The results of this study convey the importance of muscle quality rather than muscle quantity during the process of aging in elderly men and women

Delmonico, Harris, Lee, Visser, Nevitt, Kritchevsky, Tylavsky, and Newman, 2007 (7)

The use of residuals to determine sarcopenia classifications

The purpose of this study was to compare sarcopenia classification methods and the prediction of physical function decline in the elderly. Subject data was taken from 2,976 men and women aged 70 to 79 years living in the United States who participated in the Health, Aging, and Body Composition (Health ABC) Study. Decline in physical function was determined during an average follow-up period of 5 years. Body composition measurements were determined from DXA using a Hologic system. Relative lean mass was calculated as ALM divided by height squared and sarcopenia cut-off points were determined as the lowest 20% of the study distribution (5.67 kg·ht^{-2} for women and 7.25 kg·ht^{-2} for men). The 20th percentile of residuals using sex-specific linear regression from the relationship between ALM on height and fat mass were used an alternative method of defining sarcopenic individuals. Lower extremity performance was determined from chair stand, gait speed, and standing balance using a total score of 12 with impairment designation as a score of less than 10. Persistent lower extremity limitation was determined by self-report and defined as having difficulty walking a quarter-mile or climbing 10 steps without rest for two consecutive six-month intervals. The residuals classification method yielded a greater association between sarcopenia in women and incidence of persistent lower extremity limitation than in those without sarcopenia. Decline in lower extremity function was greater in sarcopenic men and women than normal muscle mass subjects using the residuals method. The relative ALM method did not show the same sensitivity as the residuals method. The conclusion of this study was that the residuals method may be a better predictor of disability than the relative ALM method because it accounts for the fat mass.

The importance of the classification of elderly obesity

Davison, Ford, Cogswell, and Dietz, 2002 (20)

Body fat percentage and BMI are associated with functional limitations

The purpose of this study was to evaluate the relationship between various body composition measures and functional limitations in elderly men and women. Subject data was taken from 2,917 elderly men and women over the age of 70 years old from the United States who participated in the National Health and Nutrition Examination Survey III (NHANES III). Functional limitations were assessed using a series of self-reported ability to complete 6 separate tasks with those reporting limitation in more than half of the tasks being considered functionally limited. Body fat percentage was estimated using the previously described prediction equation by Baumgartner et al. (9). Muscle mass was estimated from bioelectrical impedance analysis data using a prediction equation developed by Janssen et al. Body mass index categories and sarcopenic obesity groups from the body fat percentage and muscle mass were determined for the overall group. Odds ratios and prevalence ratios from logistic regression showed that a BMI greater than 30 $kg \cdot m^{-2}$ was significantly associated with functional limitations. Body fat percentages in the highest quintile were also significantly associated with functional limitations, while muscle mass and sarcopenic obesity groupings were not associated. Interestingly, the relationship between body composition and functional limitations was shown to be similar between ethnic groups. The results of this investigation showed that increased body fat percentage and BMI are associated with a greater possibility of functional limitations.

Jankowski, Gozansky, Van Pelt, Schenkman, Wolfe, Schwartz, and Kohrt, 2008 (49)

Adiposity as a predictor of measured and self-reported physical function; BMI as a substitute for adiposity in the prediction of physical function

The purpose of this study was to examine the relationship between body composition and either performance-based or self-reported physical function in older, healthy men and women. A sample of 109 independently living men and women greater than 60 years old were recruited to complete a dual-energy X-ray absorptiometry (DXA) scan and two measures of physical function. The DXA scan was used to assess body mass, fat mass, and appendicular mass and these measures were normalized to height squared to determine body mass index (BMI), fat index (FI), and appendicular skeletal muscle index (ASMI). DXA scans were completed using both Lunar and Hologic systems. The values from the Hologic system were adjusted using orthogonal regression to reflect values similar to those provided by the Lunar system. Physical function performance was determined by the Continuous Scale-Physical Functional Performance (CS-PFP) test which consists of 16 tasks that represent activities of daily living of varying difficulty, and the Medical Outcomes Short Form-36 ($SF36_{PF}$) which consists of questions to assess perceived physical ability. BMI was found to be similar between men and women, while FI was higher and ASMI was lower in women than men. CS-PFP and $SF36_{PF}$ scores were significantly different between normal weight and obese individuals using BMI and between the high and low FI tertiles. CS-PFP and $SF36_{PF}$ scores were not significantly different between sarcopenic and normal subjects as measured by ASMI cutpoints ($kg \cdot m^{-2}$) or by ASMI tertiles. Linear regression analysis to predict CS-PFP and $SF36_{PF}$ revealed BMI, and FI, but not ASMI, to be significant predictors in various models. All the examined models showed age as a significant predictor, while only models incorporating BMI were adjusted for sex. BMI and FI were shown to be independent predictors of physical performance. The results of this study showed that obesity is a better predictor of physical performance than muscle mass in the elderly and that a field-based method of obesity classification, BMI, may be as useful as laboratory-based adiposity measure, FI, in predicting physical function.

Koster, Ding, Stenholm, Caserotti, Houston, Nicklas, You, Lee, Visser, Newman, Schwartz, Cauley, Tylavsky, Goodpaster, Kritchevsky, and Harris. 2011 (44)

The association of obesity with muscle quality; adiposity as a predictor of accelerated loss of lean mass

The purpose of this study was to examine changes in leg lean mass, muscle strength, and muscle quality that occurred over the course of seven years and the relationship between these changes and body fat, insulin resistance, and adipocytokines. Subject data was taken from 2,307 men and women living in the United States from 70 to 79 years old that participated in the Health, Aging, and Body Composition study. Body fat and leg lean mass values were determined using by DXA using a Hologic system. Muscle strength was determined during concentric knee extension at 60 degrees per second using an isokinetic dynamometer with the maximum muscle torque calculated as the average of three trials. Muscle quality was calculated as the maximum torque value divided by leg lean mass. Interleukin-6 and tumor necrosis factor-α were measured from fasting blood samples. Insulin resistance was calculated as fasting insulin multiplied by fasting glucose using the homeostasis model assessment (HOMA-IR). Changes in fat mass were shown to be related to altered leg lean mass with every standard deviation increase in fat attributed to an increase in lean mass of 1.3 kilograms in men and 1.5 kilograms in women. Baseline fat mass in men and women was associated with a significant loss of 0.02 kilogram in leg lean mass per year. Fat mass was also significantly related to greater muscle strength but lower muscle quality in men and women. Adipocytokines and insulin resistance were not shown to be significantly associated with the relationship between fat mass and the increased rate of muscle loss. In conclusion, the authors determined that fat mass is inversely associated with muscle quality and is a significant predictor of lean mass loss.

Gomez-Cabello, Pedrero-Chamizo, Olivares, Luzardo, Juez-Bengoechea, Mata, Albers, Aznar, Villa, and Espino, 2011 (38)

Prevalence of overweight and obese in elderly individuals; relationship between body fat and lifestyle factors

The purpose of this study was to determine the prevalence of overweight, obese, and sarcopenic obese elderly individuals in Spain and to examine the relationship between adiposity and lifestyle parameters in this group. Subject data was taken from 3,136 non-institutionalized Spanish men and women from 65 to 92 years old that participated in the elderly EXERNET multi-centre study. Age, height, weight, percent body fat and muscle mass from bioelectrical impedance analysis, waist circumference, educational level, and walking and sedentary levels were determined. Body mass index and relative muscle mass were determined as values of body weight and muscle mass, respectively, divided by height squared. It was concluded that 84% of the sample were considered overweight or obese with a BMI greater than 25 $kg \cdot m^{-2}$ and 55.9% showed signs of central obesity as determined by a waist circumference greater than or equal to 88 centimeters in women and 102 centimeters in men. With regard to body fat percentage, 66.9% of the sample showed excess adiposity as determined by inclusion in the upper two quintiles. The two lowest quintiles for relative muscle mass were used to define low muscle mass. Sarcopenic obese individuals as determined by high body fat and low muscle mass included 14.9% of the sample (17.7% of men and 14.0% in women). In both men and women, a significant inverse relationship between an active lifestyle and body fat percentage as well as waist circumference was shown, while sedentary activity was significantly and positively associated with BMI and body fat percentage. The results of this study showed that obesity is highly prevalent in Spanish elderly individuals and that lifestyle factors are related to BMI, waist circumference, and body fat percentage.

The importance of the classification of sarcopenic obesity

Baumgartner, 2000 (39)

The distinction between sarcopenia, obesity, and sarcopenic obesity; guidelines for classification

The purpose of this study was to evaluate the health and functional status in elderly individuals according to body composition classifications considering both muscle mass and fat mass. The subject data for this study was taken from the New Mexico Aging Process Study (NMAPS) and the New Mexico Elder Health Survey (NMEHS), and included information collected from 1,283 elderly men and women over the age of 60 years old. Body composition was measured by DXA using a Lunar system for the NMAPS participant, while appendicular skeletal muscle mass was estimated from weight, height, hip circumference, grip strength, and gender (R^2=0.91, SEE=1.58kg), and body fat percentage was estimated from waist circumference, hip circumference, triceps skinfold, and gender (R^2=0.79, SEE=3.94%) for the NMEHS participants. Disability was determined using the Activities of Daily Living (ADL) and Instrumental Activities of Daily Living (IADL) questionnaires. Tinetti's instrument was used to determine balance and gait abnormalities. Sarcopenia cut-off points were designated as two standard deviations below the young adult mean for relative skeletal muscle index (RSMI=ASM/height squared). These values were previously established as 5.45 $kg \cdot m^{-2}$ for women and 7.26 $kg \cdot m^{-2}$ for men. Obesity cut-off points were designated as values greater than the median body fat percentage for the current cohort. These values were calculated as 38% for women and 27% for men. For the individuals less than 70 years old, 15% were considered sarcopenic and 2% sarcopenic obese. For the individuals greater than 80 years old, 40% were considered sarcopenic and 10% sarcopenic obese. Handgrip relative to body weight was significantly lower in the sarcopenic obesity group than the normal, sarcopenic, and obese groups. Sarcopenic obesity provides the greatest association with physical disability, balance abnormalities, gait abnormalities, and falls in the past year when compared to sarcopenia or obesity alone. The conclusion of this investigation was that the proposed body composition classifications have different association with health and functional status. The authors proposed these classifications as individual "syndromes of disordered body composition" which may require specialized programming and interventions.

Visser, 2002 (54)

Combination of low muscle mass and fat infiltration are related to lower extremity function

The purpose of this study was to examine the relationship between lower extremity body composition and function in healthy, elderly individuals. Subject data was taken from 3,075 well-functioning men and women between the ages of 70 and 79 years old living in the United States who participated in the Health, Aging, and Body Composition (Health ABC) Study. Lower extremity function was determined by a six-meter timed get up and go test as well as a timed test in which the participant stood up and sat down five times as quickly as possible. Thigh cross-sectional area, including muscle mass, intramuscular adipose tissue, and intermuscular adipose tissue, was determined by computed tomography (CT). Thigh muscle area when adjusted for total body fat was positively and significantly correlated with lower extremity function (R>0.435). Muscle attenuation, an indicator of reduced fat infiltration, was positively and significantly correlated with lower extremity function (R>0.159). When combined to predict lower extremity function, muscle area was the greatest predictor in men, but muscle attenuation was also a significant predictor. Interestingly, total body fat was the greatest determinant of lower extremity function in women, followed by muscle area. The results of this study show that both thigh muscle and fat are associated with lower extremity function when examining healthy, elderly men and women.

<u>Baumgartner, Wayne, Waters, Janssen, Gallagher, and Morley, 2004 (45)</u>

The relationship between sarcopenic obesity and disability with regard to activities of daily living

The purpose of this study was to assess the relationship between sarcopenic obesity and self-reported physical function in the elderly. The subject data was taken from 451 men and women over the age of 60 years old who participated in the New Mexico Aging Process Study (NMAPS). Physical function was determined during a follow-up period of up to eight years. Incident disability was determined by self-report using the Instrumental Activities of Daily Living (IADL) questionnaire. Appendicular skeletal muscle mass (ASM) and body fat percentage were determined by DXA using a Lunar system. Relative skeletal muscle index (RSMI = ASM/height squared) was then calculated. Previously established sarcopenia cut-off points of 5.45 $kg \cdot m^{-2}$ for women and 7.26 $kg \cdot m^{-2}$ for men were utilized for classification purposes. Obesity cut-off points were designated as values above the 60th percentile of body fat percentage for the current cohort. These values were calculated as 40% for women and 28% for men. During the initial data collection period, 5.8% of the cohort were considered both sarcopenic and obese, with men being the most likely to be included in this group. Throughout the 8-year follow-up, 17% of the overall group reported increased incident disability. The individuals in the sarcopenic obese category were the most likely to report increased disability. The non-obese groups were more likely to be physically active at baseline than the obese groups, while the obese groups were more likely to report hypertension as a prevalent condition. An increase in disability was significantly associated with age, activity level, hypertension, and arthritis/rheumatism at baseline, as well as mortality during follow-up.   The condition of sarcopenic obesity increased the odds of a drop in functional status by two to three times. The conclusion of this study was that sarcopenic obesity is a key indicator of the potential for increased disability in healthy, elderly men and women.

<u>Stenholm, Harris, Rantanen, Visser, Kritchevsky, and Ferrucci, 2008 (29)</u>

The impact of obesity and muscle strength on mobility

The purpose of this study was to examine the effects of obesity and low muscle strength on changes in walking speed and disability. The study data was from 930 healthy Italian men and women greater than 65 years old who participated in the InCHIANTI (Invecchiare in Chianti, aging in the Chianti Area) study. Body composition and mobility measures were determined for follow-up analyses at three years and six years following baseline. Body mass index was calculated for each participant and obesity was defined as greater than or equal to 30 $kg \cdot m^{-2}$. Muscle strength was measured during maximal isometric knee extension and tertiles were calculated for men and women with the lowest tertile being designated as the low muscle strength cut-off point. Walking speed was determined over a distance of four meters and self-reported mobility disability was determined as the inability to walk 400 meters or climb a flight of stairs without assistance. Individuals classified as obese and possessing low muscle strength at baseline had lower walking speed than those classified as normal, only possessing low strength, or only obese. Walking speed decline over the course of six years in individuals younger than 80 years was greatest in the low muscle, obese group at 17% compared with 2% to 8% in the other goups. Differences in walking speed decline amongst groups were no longer present in individuals greater than 85 years old with declines of 23% to 42%. The authors noted that changes in walking speed could be partly explained by muscle strength and BMI. The results of this study provide evidence that muscle strength, in addition to BMI, should be considered when addressing the risk of decreased mobility in the elderly.

Bouchard, Dionne, and Brochu, 2009 (112)

Obesity may have a greater role in physical capacity than sarcopenia

The purpose of this study was to evaluate the relationship between physical capacity and the categorization of sarcopenia and obesity. The study data was from 904 healthy Canadian men and women between the ages of 68 and 82 years old who participated in the NuAge (Nutrition as a Determinant of Successful Aging) observational study. Body composition was determined by DXA using a Lunar system. Appendicular skeletal muscle index (legs lean mass + arms lean mass/height squared) and percent body fat were calculated. Obesity cut-off points were taken from the guidelines of the American College of Sports Medicine with obesity in men being body fat greater than or equal to 28% and in women greater than or equal to 35%. Sarcopenia cut-off points were determined as two standard deviations below the young adult mean of previously published data. These values were 8.51 $kg \cdot m^{-2}$ for men and 6.29 $kg \cdot m^{-2}$ for women. A global physical capacity score was determined from the results of four physical capacity measures. These measures were the timed up and go, chair stand, walking speed, and one leg stand tests. Self-reported physical activity level was determined from Physical Activity Scale for the Elderly questionnaire. Self-reported sum of reported chronic conditions was determined from a modified version of the Older American Resources and Services questionnaire. 18.8% of men and 10.8% of women were classified as sarcopenic obese. The men classified as obese, regardless of sarcopenia groupings, had lower global physical activity scores than individuals classified as as normal. In women, the obese sarcopenic and nonsarcopenic groupings had lower global physical activity scores than both the sarcopenic and normal groupings. The results of this study suggested that obesity alone might have a greater association with physical activity limitations than sarcopenia or perhaps sarcopenic obesity.

Body mass index (BMI) and the elderly

Frisancho and Flegel, 1982 (2)

BMI correlated with skinfolds

The purpose of this study was to compare skinfold thickness measures to various ratios of weight and height. The study data was collected from 16,459 healthy men and women living in the United States between the ages of 18 and 74 years old who participated in the Health and Nutrition Examination Survey (HANES 1). Body mass indices included the calculation of weight to height squared, weight to height cubed, and weight to height with consideration to age, sex, and race. Skinfold measurements were taken from the triceps and subscapular regions. For comparison purposes, the body mass indices were compared to the triceps skinfold, the subscapular skinfolds, and the sum of the two skinfolds. The three body mass indices displayed similar correlation coefficients to the skinfold measurements. Correlation coefficients were greater for the subscapular skinfold than the triceps skinfold. Correlation coefficient values tended to be highest in the weight to height squared index. Weight alone accounted for 46% to 52% of the variance in skinfold thickness values, while weight to height squared accounted for approximately 58% of the variance. The results of this study showed that weight to height squared, or body mass index, is an appropriate measure of obesity in a large sample of healthy adults.

Gallagher, Visser, Sepulveda, Pierson, Harris, and Heymsfield, 1996 (36)

The relationship between BMI and body fat percentage; age and sex considerations for BMI

The purpose of this study was to evaluate the impact of age, sex, and ethnicity on body fat and its relationship with body mass index. The participants in this study were 706 healthy men and women living in New York City with an average age of approximately 48 years old who had a body mass index of less than 35 $kg\cdot m^{-2}$. Height, weight, and waist circumference were measured for all participants. Body density was determined from underwater weighing and total body water was estimated by tritium dilution. Bone mineral density was determined from DXA using a Lunar system. A four-compartment model developed by Heymsfield et al. was used to quantify body fat. Body mass index was significantly correlated with body weight, body fat percentage, and fat mass in black and white men and women. Body mass index and age were both significant predictors of body fat percentage with older individuals exhibiting higher adiposity then younger individuals with comparable BMI values. Additionally, sex was a significant indicator of body fat percentage with men having lower adiposity then women with comparable BMI values. Race did not explain any additional variance when included with BMI, age, and sex. The results of this study indicate that age and sex should be considered when using BMI as an indicator of body fat percentage.

Fried, Tangen, Walston, Newman, Hirsch, Gottdiener, Seeman, Tracy, Kop, Burke, and McBurnie, 2001 (84)

BMI category-specific cut-off points for muscle strength; the handgrip-BMI relationship as an indicator of frailty

The purpose of this study was to develop a standard definition for frailty in elderly men and women. The study data was from 5,317 healthy men and women living in the United States over the age of 65 years old who participated in the Cardiovascular Health Study. Frailty measures were determined during a follow-up period between four and seven years. The authors designated specific measures for different characteristics of frailty, including shrinking, weakness, poor endurance, slowness, and physical activity. Three or more positive scores on measures of frailty was considered indicative of frailty phenotype. Weakness was defined as grip strength in the lowest quintile of the population of men or women at baseline for a given BMI category. The weakness cut-off points for men were 32 kilograms for a BMI greater than 28 $kg \cdot m^{-2}$, 30 kilograms for a BMI between 24.1 and 28 $kg \cdot m^{-2}$, and 29 kilograms for a BMI less than or equal to 24 $kg \cdot m^{-2}$. The weakness cut-off points for women were 21 kilograms for a BMI greater than 29 $kg \cdot m^{-2}$, 18 kilograms for a BMI between 26.1 and 29 $kg \cdot m^{-2}$, 17.3 kilograms for a BMI between 23.1 and 26 $kg \cdot m^{-2}$, and 17 kilograms for a BMI less than or equal to 23 $kg \cdot m^{-2}$. Twenty percent of men and women had grip strength and BMI scores that were considered a sign of frailty and could be classified as prefrail. The results of this study provide justification for handgrip strength and BMI as indicators of frailty in the elderly.

Bedogni, Pietrobelli, Heymsfield, Borghi, Manzieri, Morini, Battistini, and Salvioli, 2001 (94)

BMI as a predictor of body fat in elderly women

The purpose of this study was to examine the effectiveness of BMI as a predictor of body fat percentage from DXA in elderly women. The participants in this study were 1,423 healthy Italian women ranging in age from 60 to 88 years old. Body mass, lean tissue mass, and fat mass were determined from DXA using a Lunar system. Linear regression was used to examine the association between BMI and lean tissue mass, lean tissue mass percentage, fat mass and body fat percentage. BMI explained 22% of the variance in lean tissue mass, 54.8% of the variance in lean tissue mass percentage, 72.9% of the variance in fat mass, and 54.8% of the variance in body fat percentage. The root mean square error percentages from the BMI regression equation for fat mass and body fat percentage were 15% and 11%, respectively. The authors noted that the root mean square error values were similar for other indirect methods of body composition estimation. Interestingly, age was not significant predictor of body fat percentage when included with BMI and sex. The authors concluded that BMI is an acceptable method of body fat estimation when conducting population studies of elderly women.

Woo, Leung, and Kwok, 2007 (37)

BMI, fat mass, and muscle mass as determinants of physical function

The purpose of this study was to explore the use of BMI as an indicator of physical function in the elderly. The participants in this study were 2,000 men and 2,000 women who were living independently and were 65 years or older. Body mass index was calculated and physical activity was assessed using the Physical Activity Scale of the Elderly. Appendicular skeletal muscle mass and fat mass were determined by DXA using a Hologic system. Handgrip strength was measured using a JAMAR handgrip dynamometer and time to walk six meters was recorded. Participants were separately classified by BMI, fat mass, and appendicular skeletal muscle mass categories. Obese individuals, as determined from BMI, had a significantly higher number of physical impairments than the normal weight individuals. The group of individuals with a BMI of 30 $kg \cdot m^{-2}$ or greater had the slowest walk times. Classification of individuals by fat mass categories was most effective method of determining minimum walk time. Handgrip strength decreased as fat mass increased and as appendicular skeletal muscle mass decreased in both men and women. The results of this study showed that BMI, fat mass, and appendicular skeletal muscle mass are determinants of different measures of physical function in older individuals.

Levitt, Heymsfield, Pierson, Shapses, and Kral, 2007 (42)

BMI regression equations for fat fraction prediction show linear associations within certain BMI ranges

The purpose of this study was to examine the relationship between BMI and body fat fraction using realistic models of increased obesity. The study data was collected from 1,356 male and female Chinese volunteers between the ages of 18 and 97 years old with BMI values between 17 $kg \cdot m^{-2}$ and 65 $kg \cdot m^{-2}$. Total body water was determined using tritium dilution and body density was estimated from underwater weighing. Body fat fraction was calculated using the three-compartment model developed by Siri. For a given BMI category, fat fraction tends to increase with age. Asians and Puerto Ricans had greater average fraction values than Caucasians, but Blacks and Hispanics display similar values. Across the examined age and BMI ranges, a linear relationship was found between BMI and fat fraction for men. In women with BMI values greater than 50 $kg \cdot m^{-2}$, a linear model overestimates fat fraction. The results of this study confirm the relationship between BMI and body fat, while describing a linear relationship for individuals with BMI values less than 50 $kg \cdot m^{-2}$.

Heymsfield, Scherzer, Pietrobelli, Lewis, and Grunfeld, 2009 (73)

Adipose tissue and skeletal muscle from MRI are associated with BMI

The purpose of this study was to compare the relative associations of skeletal muscle and adipose tissue with body mass index. The study data was from 263 men and women living in the United States between the ages of 33 and 45 years old who participated in the Coronary Artery Risk Development in Young Adults (CARDIA) study. BMI values for these individuals ranged from 24 $kg \cdot m^{-2}$ to 34 $kg \cdot m^{-2}$. Adipose tissue and skeletal muscle volumes were determined by magnetic resonance imaging (MRI). Additionally, lifestyle factors, including physical activity and alcohol intake, were calculated via questionnaires. BMI, physical activity, and alcohol intake were all found to be significantly associated with adipose tissue. Regardless of BMI, men had greater levels of skeletal muscle than adipose tissue, while women in higher BMI categories had greater levels of adipose tissue. In men, skeletal muscle and adipose tissue were both significant determinants of BMI and contributed equally to determination of BMI in independent models. In women, skeletal muscle and adipose tissue were also significant determinants of BMI, but adipose tissue (R^2=0.90) contributed a greater proportion of the variance in BMI than skeletal muscle (R^2=0.62) in independent models. The results of the study revealed that both adipose tissue and skeletal muscle are associated with BMI, but that sex-specific differences between these tissue volumes are present.

<u>Arngrimsson, McAuley, and Evans, 2009 (34)</u>

Change in BMI is related to change in lean soft tissue and body fat

The purpose of this study was to determine the effectiveness of BMI in tracking changes in body composition over the course of two years in elderly women. The study data was collected from 197 older female volunteers living in the United States between the ages of 59 and 82 years old. Testing measurements were completed at baseline with follow-up measures completed after two years. Fat mass, body fat percentage, and lean soft tissue were determined from DXA using a Hologic system. Change in BMI over two years was found to be a significant predictor of changes in fat mass (r=0.90), body fat percentage (r=0.64), and lean soft tissue when controlled for change in height (r=0.76). Fat mass and body fat percentage were linearly related to BMI, while a quadratic model provided a more concise relationship between BMI and lean soft tissue. Age and race did not improve any of the examined regression models. The results of this study showed that change in BMI is related to change in lean soft tissue, as well as body fat, in elderly women.

<u>Okorodudu, Jumean, Montori, Romero-Corral, Somers, Erwin, and Lopez-Jimenez, 2010 (108)</u>

High specificity for BMI as a measure of adiposity; BMI cut-off levels between 25 kg·m^{-2} and 30 kg·m^{-2}

The purpose of this study was to analyze the capability of body mass index to identify obesity. The study data was compiled from 25 published manuscripts including subject data from 31,968 individuals. A meta-analysis was conducted using this data to determine relevant diagnostic values. A specificity value, indicating the probability of correctly being classified as non-obese, of 0.90 and a sensitivity value, indicating the probability of correctly being classified as obese, 0.50 were calculated from the pooled data. Positive and negative likelihood ratios were greater in studies using BMI cut-off values of greater than 30 kg·m^{-2}, indicating that individuals in this grouping may be more likely to be correctly classified as obese. The results of this meta-analysis showed that BMI is very likely to correctly classify non-obese individuals as non-obese, but may incorrectly classify obese individuals as non-obese. Furthermore, this research showed that a BMI cut-off value of greater than 30 kg·m^{-2} increases the utility of this measure as an indicator of adiposity.

Handgrip strength and the elderly

<u>Lauretani, Russo, Bandinelli, Bartali, Cavazzini, Di Iorio, Corsi, Rantanen, Guralnik, and Ferrucci, 2003 (46)</u>

Handgrip as a measure sarcopenia during aging; cut-off values for mobility assessment

The purpose of this study was to determine the usefulness of muscle strength, power, and cross-sectional area in classifying disability by mobility measures in individuals throughout the aging process. The study data was from 1,030 healthy Italian men and women from 20 to 102 years old who participated in the InCHIANTI (Invecchiare in Chianti, aging in the Chianti Area) study. Isometric knee extension torque was measured by hand-held dynamometry, and lower extremity power was estimated from leg extension using a method devised by Bassey and Short. Upper extremity strength was measured by handgrip dynamometry. Calf muscle cross-sectional area was measured by peripheral quantitative computerized tomography (pQCT). Sarcopenia was defined as displaying values greater than two standard deviations from the mean for a given measure. Walking speed was determined over a distance of four meters and self-reported walking ability was determined as the distance a person could walk without difficulty. Sarcopenia, as indicated by leg extension torque, handgrip strength, muscle power, and calf cross-sectional area, was shown to increase over the lifespan in both men and women. Muscle power showed the steepest decline with age, while calf cross-sectional area showed the shallowest decline. Muscle power, leg extension torque, and handgrip strength showed similar predictive ability with regard to walking speed (<0.8 meters per second) and walking ability (<1 kilometer).

Optimal cut-off values for handgrip strength to identify walking speed dysfunction were determined as 30.3 kilograms for men and 19.3 kilograms for women, and to identify walking ability dysfunction as 32.8 kilograms for men and 20.5 kilograms for women. The results of this study show that handgrip strength is comparable to lower extremity strength and power and, possibly, superior to calf cross-sectional area in the identification of physical decline associated with aging and sarcopenia.

Syddall, Cooper, Martin, Briggs, and Sayer, 2003 (48)

Grip strength and markers of frailty

The purpose of this study was to assess grip strength as a marker of frailty in the elderly. The study data was collected from 717 men and women living in the United Kingdom between the ages of 64 and 74 years old. Grip strength was determined using a Harpenden dynamometer, while numerous measures of frailty were collected, including number of teeth, skin thickness, hearing acuity, visual acuity, blood pressure, and various blood markers. Mortality rate and the associated causes of death were determined over a four-year and ten-month follow-up period. Grip strength was significantly greater in men than women and decreased with age in both sexes. Decreased grip strength was significantly correlated with ten frailty markers in men and six markers in women, while chronological age was significantly correlated with only seven frailty markers in men and three markers in women. Grip strength was significantly correlated with all-cause mortality in men only, however, a relatively small number of women (15 compared to 37 men) died during the follow-up period. Even after adjusting for height, grip strength continued to be significantly associated with mortality in men. The results of this study show that grip strength, as opposed to chronological age, may a better indicator of frailty in similarly-aged men and women.

Sayer, Syddall, Martin, Dennison, Roberts, and Cooper, 2006 (22)

Grip strength and quality of life

The purpose of this study was to explore the relationship between handgrip strength and quality of life in older people. The study data was collected from 2,987 men and women living in the United Kingdom between the ages of 59 and 73 years old. Grip strength was determined using a Jamar dynamometer. Health-related quality of life was determined by the completion of the Short Form-36 (SF-36) questionnaire. Men and women with lower grip strength were more likely to report lower general health values, than those with higher grip strength values. This relationship was also reflected in SF-36 scores for general health and physical functioning after controlling for age, size, physical activity, and co-morbidities. For women only, grip strength was also significantly associated with the role-physical, vitality, bodily pain domains of the SF-36 measure. The results of this study show that grip strength is related to quality of life in older individuals.

Gale, Martyn, Cooper, and Sayer, 2007 (52)

Grip strength related to body composition; grip strength as an indicator of survival

The purpose of this study was to examine the relationship between body composition, grip strength, and mortality over the course of 24 years in the elderly. The study data was collected from 800 British men and women over the age of 65 years old. Testing measurements, including body mass index calculations, were completed at baseline with a 24-year follow-up with consideration to mortality. Body fat percentage was determined by skinfold thickness measurements using the Durnin and Wormesley equation. Arm muscle area was estimated from triceps skinfold and mid-arm circumference using an equation developed by Heymsfield. Grip strength was measured using isometric handgrip dynamometry. Low handgrip strength was found to be associated with increased all-cause mortality, death from cardiovascular disease, and death from cancer in men only. Grip strength was inversely correlated with age (r=-0.43). Partial correlations, adjusted for age and sex, describing the relationship with grip strength were higher for height (r=0.31), fat-free mass (r=0.28), and arm muscle area (r=0.28), than for BMI (0.11) and body fat percentage (r=0.09). BMI was significantly correlated with body fat percentage (r=0.74 for men and women) as well as fat free mass (men, r=0.73; women, r=0.79). The results of this study show that grip strength is related to body composition and mortality in older individuals. Additionally, the authors stated that muscle strength may be a more useful indicator of mortality than muscle size.

Vianna, Oliveira, and Araujo, 2007 (113)

The age-associated loss of grip strength; reference values

The purpose of this study was to examine the age and sex differences in handgrip strength. The study data was collected from 1,787 Brazilian men and women between the ages of 18 and 91 years old. Handgrip strength was measured using a digital handgrip dynamometer. Height and weight were also collected for all study participants. The relationship between grip strength and age was best illustrated using a quadratic model with age accounting for 30% of the strength variance in men and 28% of the variance in women. Grip strength was shown to decline at faster rate after the age of 30 years old in men and 50 years old in women. The results of this study provide handgrip strength reference values and further details the age-associated loss of muscle strength in men and women.

Cooper, Kuh, and Hardy, 2010 (40)

Hazard ratios for handgrip and mortality

The purpose of this study was to analyze the studies published examining the relationship between handgrip strength and mortality in older individuals. The study data was compiled from 14 published manuscripts including subject data from 53,476 individuals. A meta-analysis using this data was conducted to determine hazard ratios for mortality. Increased grip strength was found to be significantly associated with lower mortality (hazard ratio=0.97 per 1 kilogram increase in grip strength). When comparing the lowest and highest quartile, the hazard ratio increased to 1.67. Furthermore, the hazard ratio for mortality increased with each subsequent decrease in quartile ranking of grip strength. Hazard ratios comparing the lowest and highest quartiles tended to be lower in studies examining sample groups younger than 60 years old and with follow-up periods greater than 20 years. The results of this study show that grip strength is an effective measure of mortality.

Sallinen, Stenholm, Rantanen, Heliovaara, Sainio, and Koskinen, 2010 (5)

Grip strength cut-off points for mobility with consideration to BMI

The purpose of this study was to calculate grip strength values with consideration to BMI that correspond with varying levels of mobility dysfunction. The study data was from 3,392 Finnish men and women aged 55 years or older who participated in the Health 2000 Survey. Handgrip strength was determined using a handheld dynamometer. Height and weight were measured and BMI was calculated. Self-reported mobility limitation was determined as the inability to walk 0.5 kilometers or climb a flight of stairs without difficulty. Grip strength cut-off points were determined by calculating the value where grip strength values were balanced according to specificity and sensitivity for the prediction of mobility limitation. After adjustment for age, handgrip cut-off values of 37 kilograms for men and 21 kilograms for women were designated for mobility limitation. When considering BMI classifications, handgrip cutoff values of 33 kilograms and 20 kilograms for normal weight men and women, respectively; 39 kilograms and 21 kilograms for overweight men and women, respectively; and 40 kilograms and 23 kilograms for obese men and women, respectively. Odds ratios for men and women indicated handgrip strength below the designated cutoff points would be associated with 2.73 times the odds of mobility limitation than handgrip strength above the cutoff points. The results of this study illustrate the ability of grip strength to predict mobility limitations and cutoff points were designated for men and women with respect to BMI classification.

The use of dual-energy x-ray absorptiometry (DXA) in the assessment of appendicular skeletal muscle index and body fat percentage

Gallagher, Visser, deMeersman, Sepulveda, Baumgartner, Pierson, Harris, and Heymsfield, 1997 (35)

The relationship of height, weight, age, and gender with appendicular skeletal muscle mass; age-related loss of muscle mass

The purpose of this study was to examine the loss of skeletal muscle mass in elderly men and women using DXA and total body potassium (TBK) measurements. The study data was collected from 284 men and women living in the United States aged 18 years or older with a BMI of less than 36 $kg \cdot m^{-2}$. Height and weight were recorded and BMI was calculated for all participants. Fat mass, fat-free mass, and total appendicular skeletal muscle mass (TASM=leg lean mass + arm lean mass) were determined from DXA using a Lunar system. TBK (^{40}K) was determined using St. Luke's 4-π whole body counter. TASM was negatively correlated with age, and positively correlated with body weight, height, fat-free mass, and TBK for men and women. Height and weight each explained greater than 60% of the TASM variance in men (African-American and Caucasian) and Caucasian women (R^2= 39% in African-American women). The addition of age in the model explained an additional 3 to 19% of the variance in TASM. Height, weight, age, and gender explained greater than 80% of the variance in TASM. TBK was also found to significantly correlated with TASM (r=0.93). Lastly, the author devised body composition estimates for a Reference Man and Reference Woman at the age of 20 years and the age of 70 years. TASM decline was calculated to be 0.40 kilograms per decade in women and 0.80 kilograms per decade in men. The results of this study detail the relationship of height, weight, age, and gender with TASM, while highlighting the loss of TASM with aging.

<u>Baumgartner, Waters, Gallagher, Morley, and Garry, 1999 (1)</u>

Factors related to loss of muscle mass and grip strength with aging

The purpose of this study was to explore the effects of physical activity, hormone, nutrition, and disease on age-related alterations in strength and body composition. The subject data was taken from 201 men and women ranging in age from 65 to 97 years old who participated in the New Mexico Aging Process Study (NMAPS). Appendicular skeletal muscle mass (ASM) and body fat percentage were determined by DXA using a Lunar system. Grip strength was measured using a Takei dynamometer. Health status was determined by physical examination. Dietary intake and physical activity were determined by self-report using three-day food records and the health insurance plan (HIP) questionnaire, respectively. Sex hormone and IGF1 concentrations were estimated from blood samples and subsequent assays. Muscle mass and grip strength were both significantly associated with age. Significant correlations were found between muscle mass and testosterone, physical activity, heart disease, and IGF1 in men, and fat mass and physical activity in women. Significant correlations were found between grip strength and muscle mass and age in men, and age, muscle mass, and IGF1 in women. The results of this study relate the multifactorial association of muscle mass and grip strength in elderly men and women.

Li, Ford, Zhao, Balluz, and Giles, 2009 (62)

DXA reference data; body fat percentage and fat-free mass prediction equations

The purpose of this study was to analyze body composition measurements from DXA using a large heterogeneous, cross-sectional sample of data. Subject data was taken from 13,066 men and women from the United States who participated in the National Health and Nutrition Examination Survey (NHANES). Anthropometric values, including height, weight, and triceps skinfold thickness, were recorded and BMI was calculated for all participants. Fat mass, body fat percentage, and fat-free mass values were determined by DXA using a Hologic system. Body fat percentage was approximately 12% higher, and fat mass 5 kilograms greater, in women than men for the entire sample, while men had approximately 18 kilograms of fat-free mass. Fat mass and body fat mass percentage increased through the age of 55 years old in women and 65 years old in men followed by a steady decrease. Fat-free mass showed a decreasing trend with age in both men and women across the lifespan. There was a significant interaction between age and BMI on body fat percentage, total body fat, and fat-free mass in both men and women. Body fat percentage cutoff values according to percentile rankings were presented for sex, race, and age groupings. A prediction equation for the estimation of body fat percentage from BMI, triceps skinfold thickness, age, and ethnicity yielded and R^2 value of 0.85. Prediction equations for fat mass and fat-free mass were derived from weight, height, age, and ethnicity both yielding R^2 values of 0.94. The results of this study DXA reference values for body fat percentage, fat mass, and fat-free mass. Furthermore, prediction equations for these values using field-based testing measures are provided.

Sun, van Dam, Spiegelman, Heymsfield, Willett, and Hu, 2010 (95)

BMI reflects similar correlations with obesity-related factors as DXA body fat estimates

The purpose of this study was to compare the relationship of DXA and anthropometric measurements to factors associated with obesity and metabolic syndrome. Subject data was taken from 31,126 men and women from the United States that participated in the National Health and Nutrition Examination Survey (NHANES). Anthropometric values, including waist circumference, were recorded and BMI was calculated for all participants. Body fat percentage was determined by DXA using a Hologic system. Body composition comparisons were only conducted using 8,773 participants who completed DXA measurements. Obesity-related factors recorded for this study included: blood pressure, cholesterol levels, triglyceride, fasting blood glucose, fasting serum insulin, serum C-reactive protein. Metabolic syndrome was determined using modified criteria from the National Cholesterol Education Program's Adult Treatment Panel III. BMI was found to be significantly correlated with total body fat mass (r=0.92) and body fat percentage (r=0.78) from DXA. Significant partial correlations for blood pressure values, HDL cholesterol, triglyceride, C-reactive protein, fasting blood glucose, and fasting insulin were shown for BMI and DXA body fat percentage. Interestingly, the authors noted that a secondary investigation showed BMI to be more closely related to DXA than bioelectrical impedance analysis values. Odds ratios for BMI (OR=2.97) and DXA body fat percentage (OR=1.64) in men, reflecting the association of these measures with metabolic syndrome, were also similar. The results of this study show that BMI provides a valid proxy measure of DXA fat estimates through similar associations with obesity-related markers and metabolic syndrome inclusion criteria.

Sanada, Miyachi, Yamamoto, Murakami, Tanimoto, Omori, Kawano, Gando, Hanawa, Iemitsu, Tabata, Higuchi, and Okumura, 2010 (88)

Prediction models of sarcopenia using field-based measurements

The purpose of this study was to develop prediction models for skeletal muscle index from DXA to classify individuals as sarcopenic. The study data was collected from 1,894 Japanese men and women between the ages of 18 and 85 years old. Participants were split into young adult (≤40 years) and older adult (≥40 years) groups by age. Anthropometric values, including waist circumference, were recorded and BMI was calculated for all participants. Grip strength was also determined. Appendicular skeletal muscle mass (ASM) and body fat percentage were determined by DXA using a Hologic system and skeletal muscle index calculated as ASM divided by height squared. Skeletal muscle index cutoff values for sarcopenia and predisposition to sarcopenia were determined as two standard deviations (men=6.87 $kg \cdot m^{-2}$; women=5.46 $kg \cdot m^{-2}$) and one standard deviation (men=7.77 $kg \cdot m^{-2}$; women 6.12 $kg \cdot m^{-2}$) below the young adult group mean, respectively. When examining the older adult group, BMI and grip strength were found to be significantly greater in the normally classified individuals compared to presarcopenic individuals for both men and women. Interestingly, body fat percentage did not differ between these two groups. Skeletal muscle index was significantly correlated with age in men (r=0.410) and women (r=0.287) over the age of 40 years old. Grip strength in the older adult group was significantly correlated with skeletal muscle index in both men (r=0.478) and women (r=0.372), but only with body fat percentage in women (r=-0.216). Using stepwise regression analysis, BMI and waist circumference in men and BMI, grip strength, and waist circumference in women were found to be significant predictors of skeletal muscle index. Prediction equations for skeletal muscle index using BMI resulted in R^2 values of 0.56 (SEE=0.35) and 0.45 (SEE=0.14) in men and women, respectively. Adding grip strength to the equation in women improved the model, resulting in an R^2 value of 0.56 and an SEE of 0.15. Final prediction equations for men, using BMI, waist circumference, and age, and women, using BMI, grip strength, and waist circumference, were developed. Coefficients of determination between the DXA-measured skeletal muscle index and predicted skeletal muscle index were 0.733 for men and 0.605 for women. The results of this study provide prediction equations for skeletal muscle index from DXA using field-based measurements in older Japanese men and women.

Cawthon, Fox, Gandra, Delmonico, Chiou, Anthony, Caserotti, Kritchevsky, Newman, Goodpaster, Satterfield, Cummings, and Harris, 2011 (13)

Adiposity and performance as risk factors for disability

The purpose of this study was to examine the relationship between variables grouped by strength, performance, adiposity, and lean mass and disability risk in elderly individuals. Subject data was taken from 1,221 elderly men and women, 70 to 80 years old, living in the United States who participated in the Health Aging and Body

Composition (Health ABC) Study. Disability status was recorded for an average follow-up period of six years. Height and weight were recorded and BMI was calculated for all participants. Body composition measurements, including fat and lean mass estimates of the total body, arms, and legs, were determined from DXA using a Hologic system. Thigh muscle cross-sectional area and density were determined from computed tomography (CT) scans. Isometric knee extension strength via maximal torque at 60 degrees per second was measured using a KinCom dynamometer. Handgrip strength was measured using a Jamar dynamometer. Physical performance measures included walking speed over six meters and chair stands per second. Disability risk was determined by the need of equipment to walk, assistance during activities of daily living, and the presence of mobility limitations as demonstrated by the inability to walk a given distance or climb ten steps. Grip strength was significantly correlated with total body lean mass (r=0.38) and body fat percentage (r=-0.14). Factor analysis was performed and the variables were grouped in three disability risk factor components, including adiposity (fat mass, weight, and muscle density), strength and lean body mass (lean mass, weight, and strength), and physical performance (walking speed and chair stand). Adiposity accounted for 44.7% of the disability risk variance in men and 51.3% in women. Strength and lean body mass accounted for 19.5% of the disability risk variance in men and 15.4% in women. Physical performance accounted for 9.9% of the disability risk variance in men and 9.0% in women. The three factor components accounted for 77.1% and 75.7% of the variance in men and women, respectively. An increase in adiposity was determined to increase the odds of disability risk by 30% in men and 60% in women.

Change in strength and lean body mass was not associated with a change in disability risk. An increase in physical performance was determined to decrease the odds of disability risk by 49% in men and 35% in women. The results of this study identified adiposity and physical performance as being related to disability risk in elderly men and women.

Isoperformance curves and decision-making analysis

<u>Kennedy, 1988 (28)</u>

Isoperformance curves and task analysis

The purpose of this study was to develop isoperformance curves to explore the relationship between gender and screen size on the ability to complete simulated air combat maneuvering. The study data was taken from 24 male and female volunteers from the University of Central Florida. Each participant was asked to complete the same air combat maneuver by controlling a simulated attack drone using an Atari gaming system five times per day for eight days. Participants were split into two groups, one of which completed each session on a big screen television (45 centimeters) and the other on a small screen television (20 centimeters). Each air combat maneuver session lasted 137 seconds and the average number of hits was recorded for the five sessions on each testing day. Men had a larger number of hits per session than women throughout the eight testing days. The size of the screen had no effect on the number of hits per session. Furthermore, no interaction between these two variables was present. A regression model for the number of hits when considering the sex, screen size, number of testing sessions was completed. Separate isoperformance curves for big and small screen televisions were developed to highlight the relationship between sex and the number of testing days to achieve an average of 13 hits. When examining this relationship, men needed approximately two days regardless of screen size, while women needed five days using a big screen and seven days using a small screen. The results of this study demonstrate the use of isoperformance curves in the analysis of task aptitude and training time.

Kennedy, 1992 (105)

Simple method of isoperformance curve development and personnel decisions

The purpose of this study was to develop isoperformance curves to explore the relationship between baseline job aptitude and training years on job performance. The study data was taken from 434 soldiers who were Level 1 turret mechanics. Job aptitude was determined as the composite score on the Armed Services Vocational Aptitude Battery (ASVAB). The soldiers were placed into aptitude groups, Low (≤100), Middle (101-111), and High (≥112), according to their ASVAB score. Job performance was determined as the score on the Skill Qualification Test (SQT), of which there are five proficiency tests each pertaining to a specific skill level (1-5). For the purpose of this investigation, only those soldiers who progressed from SQT-1 in year 1 to SQT-2 in year 2, and subsequently to SQT-3 in year 3 were examined. An SQT score 70 was considered a passing score and both the High and Middle aptitude group median scores were above the SQT-1 threshold at baseline. The goal of 90% proficiency, or 9 out of 10 soldiers rating above a 70 score, on the SQTs was set for each group. When considering the 10% percentile, all three aptitude groups were below a passing SQT score of 70 and only the High aptitude group would progress above this threshold by year 3. Isoperformance curves were constructed by plotting the time needed for each ability group to become 50% proficient because the lower ability groups did not reach 90% proficiency over the course of the study. As such, the High ability group was 50% proficient at baseline, while the Medium ability group needed 0.35 years and the Low Ability group needed 0.75 years. The results of this study outlined a simple method of analyzing job performance as a function of aptitude and training time.

<u>Jones, 2000 (55)</u>

Improved method of isoperformance curve development and personnel decisions

The purpose of this manuscript was to highlight the use of isoperformance curves in the process of decision-making with regard to personnel decisions. An example using 461 soldiers who were M1 Abrams turret mechanics was provided. Job aptitude was determined as the Mechanical Maintenance score on the Armed Services Vocational Aptitude Battery (ASVAB). M1 Abrams turret mechanics were required to have a minimum Mechanical Maintenance of 100. Job performance was determined as the score on the Skill Qualification Test (SQT) and criterion scores of 60 and 65 with a 0.90 probability of proficiency were set. SQT for each soldier was determined monthly over the course of 54 months. A regression model was formed using time on the job and Mechanical Maintenance scores to estimate SQT values. In order to construct isoperformance curves, this equation was solved for time on the job, and the SQT criterion values and Mechanical Maintenance scores were used. Analyzing the isoperformance curves revealed that it would take 12 months for a soldier who scored 117 in Mechanical Maintenance to achieve an SQT score of 65, while a soldier who scored 100 in Mechanical Maintenance would need 46 months to achieve the same level. Furthermore, the solider with a Mechanical Maintenance score of 100 would only need 12 months to achieve an SQT score of 60. The example provided in this manuscript offers a more comprehensive approach to isoperformance curve design.

de Weck and Jones, 2006 (30)

Isoperformance curves in relation to team sports performance

The purpose of this manuscript was to provide examples of the use of isoperformance curves in process of balancing variables in order to achieve a desirable performance level as opposed to performance maximization. An example using statistical data for overall team runs batted in (RBI), overall team earned run average (ERA), and final standings for a large group of major league baseball teams was provided. The final standings value were considered as a measure of performance and calculated as the fraction of games won over the course of a season with a criterion value of 0.550 with a probability of 0.80 probability of proficiency determined. An empirical model was used to determine the final standings value as a function of batting ability (RBI) and pitching ability (ERA). In order to construct isoperformance curves, this equation was solved for RBI, and the final standings criterion values and ERA were used. Additional curves corresponding to varying final standings levels were developed. When analyzing the isoperformance curves, two teams could be compared and personnel decisions could be made regarding specific improvements in batting or pitching. The case was made for two teams with similar RBI values that may be differentiated in the final standings by differences in ERA. The example provided in this manuscript details the use of isoperformance curves in relation to team performance in sports.

Morton, 2009 (68)

Isoperformance and critical velocity in team selection

The purpose of this manuscript was to present the use of the critical velocity concept as a method of utilizing isoperformance curves during team selection procedures. Rowing is offered as an example with a competition distance of 2000 meters. Criterion values for the performance times of 333.3, 400, 500, and 666.7 seconds were determined. A linear regression equation between values for distance and time to exhaustion provided the variables, critical velocity, the slope of the regression line, and anaerobic distance capacity, the y-intercept. This relationship was presented as a trade-off function between critical velocity and anaerobic working capacity. In order to construct isoperformance curves, the slope-intercept form of the regression line was solved for distance, which is set to 2000 meters, and time to exhaustion criterion values are set to produce four distinct curves. Individual critical velocity and anaerobic distance capacity values for a group of rowers were plotted against the isoperformance curves. From this graphical presentation, groupings of athletes were easily identified with respect to potential performance values and team selection procedures can be aided. Both linear and nonlinear critical velocity models were evaluated and team pursuit cycling was suggested as another sport with potential for similar application of this model. The example provided in this manuscript utilizes an existing physiological model that lends itself to isoperformance curve development which may enable a structured method of decision-making in athletics.

<u>Fukuda, Kendall, Smith, Dwyer, and Stout, 2010 (31)</u>

Physiological profiles and training needs using isoperformance curves in rowers

The purpose of this study was to compare athletes of different skill levels using isoperformance curves and assess subsequent training needs. The study data was taken from 35 collegiate female rowers. The sample consisted of both novice (< one year of experience) and varsity (> one year of experience) rowers. The athletes completed time trials for distances of 400, 600, 800, and 1,000 meters. Critical velocity and anaerobic rowing capacity were determined using the slope-intercept equation as a form of regression between time and total distance. Critical velocity was significantly greater in the varsity group compared to the novice group, while anaerobic rowing capacity was similar between groups. Criterion values for the performance times of 429, 448, and 464 seconds were determined. As described above, isoperformance curves were developed for the criterion performance times which were classified as elite, collegiate, and junior level times, respectively. Individual critical velocity and anaerobic distance capacity values for the entire group of rowers were plotted against the isoperformance curves. Only six of the varsity rowers were shown to be classified as possessing the qualities needed to perform above the junior level isoperformance curve. In order to further utilize this systematic approach, the authors suggested demarcating the athletes into quadrants within this analysis. Each subgroup of athletes would fall into a category that would fall above and below the mean values of the overall group for critical velocity and anaerobic rowing capacity. Subsequently, each of these subgroups would be given training programs according to specific metabolic training needs in order to improve performance. The results of this study further characterized the use of isoperformance curves in an effort to devise training needs in athletes.

Fukuda, Smith, Kendall, Cramer, and Stout, 2012 (70)

Isoperformance curves and critical velocity as an alternative to the two-mile running test

The purpose of this study was to propose the use of isoperformance curves and the critical velocity test as an alternative to the two-mile running test. The study data was taken from 78 male and female college-aged volunteers. The study participants were asked to complete a graded exercise test to determine maximal oxygen uptake and four treadmill running bouts of varying percentages of peak velocity. Critical velocity and anaerobic running capacity were determined using the slope-intercept equation as a form of regression between time and total distance. Criterion values for theoretical two-mile run times associated with scores on the Army Physical Fitness Test were determined. As described above, isoperformance curves for men and women were developed for the criterion performance times associated with Army Physical Fitness Test two-mile run scores between 0 and 100 with a minimum passing standard of 70. Individual critical velocity and anaerobic running capacity values for each participant were plotted against the isoperformance curves. Of the 78 participants, 54 were estimated to have achieved the minimum passing stand of 70. Training needs were addressed by overlaying horizontal and vertical lines representing quartiles for critical velocity and anaerobic running capacity. Metabolically-specific training programs were then recommended for each subgroup of participants. Lastly, a prediction equation with an R^2 value of 0.805 (SEE=3.24) for maximal oxygen uptake was developed using critical velocity and anaerobic running capacity. The results of this study established a systematic alternative to the two-mile running test using isoperformance methodology and the variables from the critical velocity test.

CHAPTER III

METHODS

Participants

Baseline values from 107 healthy Caucasian men and women over the age of 65 years old who participated in a separate longitudinal study were used for this investigation. This study was approved by The University of Oklahoma Health Sciences Center Institutional Review Board for Human Subjects (Appendix D). All participants completed a written informed consent during the original investigation. A primary objective of this investigation was to develop prediction equations from field-based measurements to predict relative skeletal muscle index (RSMI) and body fat percentage (FAT%) using multiple regression procedures. However, a minimum number of subjects must be available for the development of these models in order to be valid (99). Therefore, based on the recommendations of Vincent (2005), the current sample size meets these requirements with the possible inclusion of up to 10 independent variables in order to generalize the results.

Research Design

All participants completed the requisite measurements in a single testing day. Participants were instructed to avoid exercise for at least 24 hours prior to testing. Proper hydration status via specific gravity (Usg < 1.030) was determined from a urine sample before the testing session commenced. Following a 12-hour fast (*ad libitum* water intake was allowed up to one hour prior to testing), each participant's height, body mass, handgrip strength, and body composition from dual-energy x-ray absorptiometry (DXA) was measured. Body mass index (BMI), relative skeletal muscle index (RSMI), and body fat percentage (FAT%) were then calculated. From the BMI and handgrip strength values, separate prediction equations were developed for FAT% and RSMI. Lastly, previously established cutoff values for obesity and sarcopenia in the elderly were used to develop isoperformance curves. The resulting isoperformance curves were then compared to individual predictor values for BMI and handgrip strength.

Variables

Predictor variables were sex and values determined from field-based testing measures consisting of BMI and handgrip strength. Criterion variables were DXA-derived values for RSMI and FAT%. Additional variables examined included age, height, body mass, leg lean mass, arm lean mass, and appendicular lean mass.

Instrumentation

- Dual-energy x-ray absorptiometry (software version 10.50.086, Lunar Prodigy Advance, Madison, WI)
- Hand-held refractometer (Model CLX-1, precision = 0.001 +/- 0.001, VEE GEE Scientific, Kirkland, WA)
- Digital hand-held handgrip dynamometer (DHS-176, Detecto, Webb City, MO)
- Standard medical scale (439 Physician’s Scale, Detecto, Webb City, MO)

Body Mass Index (BMI)

Height and body mass were measured with a calibrated standard medical scale (439 Physician’s Scale, Detecto, Webb City, MO). Body mass index was then calculated as body mass divided by height squared.

Handgrip Strength

Handgrip strength was measured with a digital handgrip dynamometer (DHS-176, Detecto, Webb City, MO). Each participant was asked to stand with his or her dominant arm adducted at the side with a 90 degree flexion at the elbow. Participants were asked to squeeze the handle as forcefully as possible for 3 to 5 seconds with a single hand, and advised against holding their breath during the test. The force was measured in kilograms. The participants completed three trials with the average of the trials used as the final handgrip strength value. Test-retest reliability and validity investigations using similar equipment and protocols have resulted in correlation coefficients of greater than 0.80 (41, 47).

Dual-Energy X-Ray Absorptiometry (DXA)

DXA (software version 10.50.086, Lunar Prodigy Advance, Madison, WI) was used to estimate total body fat mass and segmental lean mass. Body fat and lean mass values were calculated using the DXA software. Each day prior to testing, a quality assurance phantom was performed and passed. Before each test, the participant's height, weight, sex, and ethnicity were entered into the computer program. The participants were asked to remove all metal, thick clothing, and heavy plastic which could interfere with the DXA scans. The participants were positioned on the table within 60-centimeter scanning area in the supine position with arms at the sides, legs extended, feet together, and hands pronated and flat on the table. Velcro straps were placed around the ankles so that the participant would not have to hold his or her feet together for the duration of the scan. Total body mode was selected for each scan, and scanning thickness was determined by the DXA software. All DXA scans were performed by a certified enCORE^{TM} software operator. Previous test-retest scans of 10 men and women for FAT% and lean mass produced a technical error of measurement (TEM) of 0.71% and 0.67 kilograms, respectively, with coefficients of variation of 2.85% and 1.27%, respectively.

Relative Skeletal Muscle Index

Segmental lean mass was determined using specific regions of interest for the arms and legs as estimated by the DXA software and modified by a certified enCORE^{TM} software operator. The right and left arm lean mass region of interest was demarcated from the thorax by a vertical cut line bisecting the head of the humerus. The right and left leg lean mass region of interest was demarcated from the thorax by an angled cut line bisecting the neck of the femur. The sum of the arm lean mass and leg lean mass was defined as the appendicular lean mass. Relative skeletal muscle index (RSMI) was calculated as appendicular lean mass divided by height squared.

Body Fat Percentage

Body fat percentage (FAT%) was provided by the DXA software and calculated as the quotient of fat mass and total mass.

Relative skeletal muscle index (RSMI) and body fat percentage (FAT%) Prediction Equations

After dividing the sample into two equal groups, linear regression analyses were used to generate two separate prediction equations to determine RSMI and FAT% from sex, BMI, and handgrip strength, respectively. Internal double cross-validation analyses of these equations were conducted to determine the similarities in constant error (CE), total error (TE), coefficient of determination (R^2), and standard error of the estimate (SEE) (82). The cross-validation was completed by using the prediction equation of one sample to estimate the RSMI or FAT% values for other sample. If the values for the preliminary analyses were comparable, additional prediction equations for RSMI and FAT%, using the entire sample, were developed.

Isoperformance Curves

Separate RSMI and FAT% isoperformance curves were constructed for men and women to correspond with previously established cutoff values for sarcopenia and obesity in the elderly. The regression equation for RSMI was modified so that RSMI was set to a fixed value to demarcate between normal, sarcopenic, and pre-sarcopenic individuals, while sex was designated as either male or female. The regression equation for FAT% was modified so that FAT% was set to a fixed value to demarcate between normal, overweight, and obese individuals, while sex was designated as either male or female.

Statistical Analysis

PASW Statistics (V. 18.0, SPSS Inc., Chicago, IL) was used for all statistical comparisons. One-way analysis of variance (ANOVA) was performed to determine differences in age, height, weight, BMI, handgrip strength, and DXA-derived body composition values between the male and female groups. Bivariate correlation analyses were performed to determine the relationships between BMI, FAT%, handgrip strength, and RSMI. Linear regression was used to determine cross-sectional trends for age and BMI, handgrip strength, FAT%, and RSMI by examining the slopes and intercepts of these relationships. Bivariate correlation analyses were performed to determine the relationship between age and BMI, FAT%, handgrip strength, and

RSMI. Prevalence values were calculated as the number of individuals classified within a given body composition phenotype divided by the number of individuals in the overall group.

During the double cross-validation, paired samples t-tests were used to compare the actual and predicted values for RSMI and FAT% from Sample A and Sample B. Calculation and comparison of CE, TE, R^2, and SEE values was completed using a custom-written software program (LabView v8.5, National Instruments, Austin, TX). Bivariate correlation analysis was performed to determine the relationship between constant error and the actual values for RSMI and FAT% from Sample A and Sample B. The RSMI and FAT% prediction equations from the overall group were calculated as previously described. Multicollinearity between sex, BMI, and handgrip strength was evaluated using tolerance and variance inflation factors. Correlation coefficients and bias ± 95% limits of agreement (LOA), as represented by Bland-Altman plots (11), were used to assess the relationships between observed and predicted RSMI and FAT % values.

A type I error rate of less than or equal to 5% was considered statistically significant for all analyses. Individual BMI and handgrip strength values were plotted on the x- and y-axes, respectively, and isoperformance curves for RSMI and FAT% cutoff values were overlaid using Microsoft Excel (Version 2007, Microsoft Corporation; The Microsoft Network, LLC, Redmond, WA).

CHAPTER IV

RESULTS

Descriptive and anthropometric statistics for the study participants are provided in Table 1. Significant differences were found between men and women for height ($p<0.01$), weight ($p<0.01$), body mass index (BMI) ($p<0.01$), and handgrip strength ($p<0.01$) (Table 1). Table 2 provides body composition values from dual-energy X-ray absorptiometry (DXA), including body fat percentage, lean mass, appendicular lean mass, and relative skeletal muscle index (RSMI). Significant differences were found between men and women for body fat percentage (FAT%) ($p<0.01$), lean mass ($p<0.01$), arms lean mass ($p<0.01$), legs lean mass ($p<0.01$), appendicular lean mass ($p<0.01$), and RSMI ($p<0.01$). No significant difference was found for fat mass between men and women ($p=0.805$) (Table 2). The results from the bivariate correlation analyses for body mass index, handgrip strength, body fat percentage, and relative skeletal muscle index calculated from the overall group, men and women are listed in Table 3, Table 4, and Table 5, respectively.

The slope of the regression for BMI with age was significantly different from zero ($m=-0.122$), indicating that BMI for the overall group trended significantly downward with age, however, no decreases were shown for men or women (Figure 1). Handgrip strength significantly decreased with age for the overall group ($m=-0.413$), as well as for men ($m=-0.548$) and women ($m=-0.257$) (Figure 2). RSMI trended significantly downward with age for men ($m=-0.060$), women ($m=-0.039$), and the overall group ($m=-0.052$) (Figure 3). FAT% did not differ with age for the overall group, men, and women as indicated by slope coefficients that were not significantly different than zero ($p>0.05$). The results from the bivariate correlation analyses for age and body mass index, handgrip strength, body fat percentage, and relative skeletal muscle index are listed in Table 6.

A comparison of individual relative skeletal muscle index and body fat percentage values for men and women as determined by DXA are provided in Figure 5 and Figure 6, respectively. Sarcopenia cut-off values of 7.26 $kg \cdot m^{-2}$ for men and 5.45 $kg \cdot m^{-2}$ for women, as suggested by Baumgartner (7), were used to differentiate amongst individual RSMI values. Elderly obesity cut-off values of 27% for men and 38% for women, as suggested by Baumgartner (7), were used to differentiate amongst individual FAT% values. Individuals with values greater than the sarcopenia cut point and less than the obesity cut point were deemed “normal”, while individuals with values less than the sarcopenia cut point and greater than the obesity cut point were deemed “sarcopenic obese”. Prevalence statistics from the DXA criterion values for normal, obese, sarcopenic, and sarcopenic obese for the current sample are provided for overall group, men, and women in Figure 13, Figure 14, and Figure 15, respectively. Using the DXA criterion values for RSMI and FAT%, 34 individuals were classified as normal (19 men and 15 women), 50 individuals were classified as obese (29 men and 21 women), 10 individuals were classified as sarcopenic (1 man and 9 women), and 13 individuals were classified as sarcopenic obese (5 men and 8 women).

The overall group was randomly divided into Sample A, consisting of data from 54 individuals (30 men; 24 women) and Sample B, consisting of data from 53 individuals (25 men: 28 women). These separate samples were used to develop prediction equations from multiple regression for FAT% and RSMI determined from DXA using BMI and handgrip strength as predictor variables. The assumption of an absence of multicollinearity amongst the predictor variables was verified with variance inflation factors (VIF) below 10 and tolerance values for sex (0.316; VIF=3.165), BMI (0.807; VIF=1.238), and handgrip strength (0.297; VIF=3.371) greater than 0.2 (26). The Sample A (Equation 1) and Sample B (Equation 2) FAT% multiple regression equations developed for the double cross-validation analysis were as follows (R^2=coefficient of determination; SEE=standard error of the estimate; Sex=0 (Men) or 1 (Women); Grip=handgrip strength)):

- Equation 1, Sample A (n=54)

$$FAT\% = (8.694 \times Sex) + (1.585 \times BMI) + (-0.198 \times Grip) - 4.987$$

$$R^2 = 0.750; \mathrm{SEE} = 4.3536\%$$

- Equation 2, Sample B (n=53)

$$FAT\% = (10.355 \times Sex) + (1.665 \times BMI) + (-0.234 \times Grip) - 6.984$$

$$R^2 = 0.755; \mathrm{SEE} = 3.6398\%$$

Table 7 presents the similar minimal error values from both FAT% prediction equations. The actual and predicted FAT% mean values were not significantly different ($p>0.05$). However, the actual FAT% values and the constant error showed a statistically significant relationship (Sample A: $r=-0.273$, $p=0.046$; Sample B: $r=-0.665$, $p<0.001$). These results justified the development of a single multiple regression equation for the overall group (45). The regression equation developed from the Overall Group (Equation 3) to predict FAT% from BMI and handgrip strength resulted in a strong relationship (adjusted R^2) with a low SEE:

- Equation 3, Overall Group (n=107)

$$FAT\% = (10.226 \times Sex) + (1.550 \times BMI) + (-0.176 \times Grip) - 5.550$$

$$Adjusted\ R^2 = 0.741; \mathrm{SEE} = 3.9937\%$$

The full results from the multiple regression analysis for FAT% are listed in Table 9. The strong relationship between the observed and predicted FAT% values from Equation 3 is illustrated using scatter and Bland-Altman plots in Figure 7 and Figure 8, respectively. Constant error was very low (9.34×10^{-8}) and only seven individuals (6.7% of the overall group) fell outside of the 95% limits of agreement. However, there was evidence of systematic bias as the slope of the regression line for the relationship between the difference and mean values was significantly different from zero ($m=0.155$; $p<0.01$). This resulted in individuals with higher FAT% values being underestimated and individuals with lower FAT% values being overestimated.

The Sample A (Equation 4) and Sample B (Equation 5) RSMI multiple regression equations developed for the double cross-validation analysis were as follows (R^2=coefficient of determination; SEE=standard error of the estimate; Sex=0 (Men) or 1 (Women); Grip=handgrip strength):

- Equation 4, Sample A (n=54)

$$RSMI = (-1.226 \times Sex) + (0.108 \times BMI) + (0.044 \times Grip) + 3.466$$

$$R^2 = 0.798; SEE = 0.6265\ kg \cdot m^{-2}$$

- Equation 5, Sample B (n=53)

$$RSMI = (-1.352 \times Sex) + (0.085 \times BMI) + (0.052 \times Grip) + 3.886$$

$$R^2 = 0.881; SEE = 0.5437\ kg \cdot m^{-2}$$

Table 8 presents the similar minimal error values from both RSMI prediction equations. The actual and predicted RSMI mean values were not significantly different ($p>0.05$). However, the actual RSMI values and the constant error showed a statistically significant relationship (Sample A: $r=-0.271$, $p=0.048$; Sample B: $r=-0.485$, $p<0.001$). These results justified the development of a single multiple regression equation for the overall group. The regression equation developed from the Overall Group (Equation 6) to predict RSMI from BMI and handgrip strength resulted in a strong relationship (adjusted R^2) with a low SEE:

- Equation 6, Overall Group (n=107)

$$RSMI = (-1.363 \times Sex) + (0.104 \times BMI) + (0.043 \times Grip) + 3.653$$

$$Adjusted\ R^2 = 0.841; SEE = 0.5771\ kg \cdot m^{-2}$$

The full results from the multiple regression analysis for RSMI are listed in Table 9. The strong relationship between the observed and predicted RSMI values from Equation 6 is illustrated using scatter and Bland-Altman plots in Figure 9 and Figure 10, respectively. Constant error was very low (-2.69×10^{-7}) and only seven individuals (6.7% of the overall group) fell outside of the 95% limits of agreement. However, there was evidence of systematic bias as the slope of the regression line for the relationship between the difference and mean values was significantly different from zero ($m=0.088$; $p<0.01$). This resulted in individuals with higher RSMI values being underestimated and individuals with lower RSMI values being overestimated.

Using the prediction values for FAT% and RSMI from Equation 3 and Equation 6, respectively, 30 individuals were classified as normal (16 men and 14 women), 58 individuals were classified as obese (35 men and 23 women), 17 individuals were classified as sarcopenic (2 man and 15 women), and 2 individuals were classified as sarcopenic obese (1 man and 1 woman). Predicted prevalence statistics for normal, obese, sarcopenic, and sarcopenic obese reflecting the aforementioned values are provided for the overall group, men, and women in Figure 13, Figure 14, and Figure 15, respectively.

Isoperformance curves representing obesity and overweight from FAT% values were developed using Equation 3. Equation 3 was solved for handgrip strength (Grip) to yield Equation 7, as follows:

- Equation 7

$$Grip = \frac{FAT\% - (10.226 \times Sex) - (1.550 \times BMI) + 5.550}{-0.176}$$

Equation 7 was modified by substituting either 27% (obese) or 23% (overweight; 38% plus the SEE from Equation 3) for FAT% and 0 (men) for Sex to produce the linear equation for the isoperformance curves illustrated in Figure 16 for men. For women, Equation 7 was modified by substituting either 38% (obese) or 34% (overweight; 38% plus the SEE from Equation 3) for FAT% and 1 (women) for Sex to produce to produce the linear equation for the isoperformance curves illustrated in Figure 17.

The prevalence statistics using predicted FAT% and the aforementioned classification of overweight and obese individuals are noted in Figure 18. There were 13 individuals (3 men and 10 women) that had predicted values of less than 23% (men) or 34% (women) for FAT% and classified as normal, while 34 individuals (15 men and 19 women) were classified as overweight and 60 individuals (36 men and 24 women) classified as obese.

Isoperformance curves representing sarcopenia and pre-sarcopenia from RSMI values were developed using Equation 6. Equation 6 was solved for handgrip strength (Grip) to yield Equation 8, as follows:

- Equation 8

$$Grip = \frac{RSMI - (-1.363 \times Sex) - (0.104 \times BMI) - 3.653}{0.043}$$

Equation 8 was modified by substituting either 7.26 kg·m^{-2} (sarcopenic) or 7.45 kg·m^{-2} (pre-sarcopenic; 7.26 kg·m^{-2} plus the SEE from Equation 6) for RSMI and 0 (men) for Sex to produce the linear equation for the isoperformance curves illustrated in Figure 19 for men. For women, Equation 8 was modified by substituting either 5.45 kg·m^{-2} (sarcopenic) or 6.03 kg·m^{-2} (pre-sarcopenic; 5.45 kg·m^{-2} plus the SEE from Equation 6) for RSMI and 1 (women) for Sex to produce to produce the linear equation for the isoperformance curves illustrated in Figure 20.

The prevalence statistics using predicted RSMI and the aforementioned classification of pre-sarcopenic and sarcopenic individuals are noted in Figure 21. There were 49 individuals (39 men and 10 women) that had predicted values of greater than 7.45 kg·m^{-2} (men) or 6.03 kg·m^{-2} (women) for RSMI and classified as normal, while 39 individuals (12 men and 27 women) were classified as pre-sarcopenic and 19 individuals (3 men and 16 women) classified as sarcopenic.

Figure 22 shows individual BMI and handgrip strength data for men from the current investigation with an overlay of the isoperformance curves representing an RSMI of 7.26 (sarcopenic; Equation 7) and a FAT% of 38% (obese; Equation 8). Figure 23 shows individual BMI and handgrip strength data for women from the current investigation with an overlay of the isoperformance curves representing an

RSMI of 7.26 (sarcopenic) and a FAT% of 38% (obese). The intersection of the obese and sarcopenia curves for men and women separates the figures into quadrants (I-IV) that can be used to different individuals into categories of normal body composition (I), obesity (II), sarcopenia (III), and sarcopenic obesity (IV). Figure 24 and Figure 25 are provided to illustrate the use of isoperformance curves in the identification of body composition phenotypes in the form of charts titled, “Clinical Phenotyping for Men (≥65 years)” and “Clinical Phenotyping for Women (≥65 years)”, respectively.

CHAPTER V

DISCUSSION

In accordance with the previously outlined hypotheses, elderly men and women can be systematically classified according to body composition categories using field based testing measurements. Body mass index (BMI), handgrip strength, and sex were found to be significant predictor variables for both body fat percentage (FAT%) and relative skeletal muscle index (RSMI). Cross-validated prediction equations for FAT% and RSMI were used to develop isoperformance curves that can be used in the classification of elderly individuals into body composition phenotype categories, including sarcopenia, obesity, and sarcopenic obesity.

Comparison of Field-Based Testing Measures

As previously shown in elderly research, BMI was greater in men than women (56, 81). Values from the current investigation are slightly lower than previously reported elsewhere for elderly men and women over the age of 65 years (38, 59), but with BMI being related to various indices of health (23, 29, 50, 111) and considering the current sample of healthy individuals this difference is not unusual. BMI for the overall group decreased with age, but this decrease did not persist when split by sex (Figure 1). Perissinotto et al. (76) showed decreases similar to the current significant (overall group) and non-significant (men and women) linear regression line slope coefficients (m=-0.12 for men and m=-0.09 for women) in Italian men and women between the ages of 65 and 84 years old. Correlation coefficients for the relationship between age and BMI (r=~-0.22) were similar to those reported by Gallagher et al. (36) for individuals between the ages of 20 and 94 years old.

Handgrip strength was greater in men than women, and values from the current investigation are similar to those previously reported for elderly men and women (9, 61, 89, 96, 99). Handgrip strength decreased with age for the overall group and for both men and women when split by sex (Figure 2). Baumgartner et al. (9) showed comparable slope coefficients from linear regression for elderly men (m=-0.648) and women (m=-0.395) between the ages of 65 and 97 years old. Correlation coefficients for the relationship between age and handgrip strength (r=-0.45 for men and r=-0.53 for women) were also similar (9). It is important to note that these similarities occurred even with a wide variety in protocols and handgrip strength measurement devices currently being utilized (86).

Comparison of DXA-Based Criterion Measures

FAT% from DXA was greater in women than men and these values are comparable to those reported elsewhere in the literature for individuals over the age of 65 years (8, 62, 90, 95). FAT% did not have a relationship with age as demonstrated by slopes from regression that were not significantly different from zero in the current sample (Figure 4), and by the lack of significance with a low correlation coefficient between the two variables. The relationship between FAT% and age in the elderly is not clear due to the reported loss of muscle during the process of aging (5). Li et al. (62) reported an increase in FAT% for women until the age of 55 years and for men until the age of 65 years with subsequent decreases over the remainder of the lifespan, while fat-free mass tended to decrease throughout adulthood regardless of sex.

DXA-derived RSMI was greater in men than women, while both mean values were similar to those previously reported in the elderly (8, 25, 48). RSMI decreased significantly with age (Figure 3) and the two variables demonstrated a significant negative relationship (r=-0.216 to -0.410). In comparison, Sanada et al. (88) showed decreases with age for RSMI with lower regression slopes as well as correlation coefficients in Japanese men and women between the ages of 41 and 85 years. Additionally, Tanko et al. (97) demonstrated a decrease in RSMI with age in healthy, physically active women throughout adulthood (18 to 85 years old). Similar to the findings in the current study, Melton et al. (67) examined the relationship between lean body mass relative to height squared and age and presented significant regression slopes of 0.07 for men and 0.02 for women over the age of 55 years.

The current investigation produced prevalence values that conflict with previous elderly research examining body composition phenotypes using the same cut-off criteria. In a study evaluating 1,283 elderly men and women, Baumgartner (7) reported prevalence as varying by age with 30% to 60% of the sample as normal, 10% to 30% as obese, 25% to 30% as sarcopenic, and 3% to 10% as sarcopenic-obese. The prevalence of obesity in the current sample is higher with 47% of the elderly men and women being classified as obese, substantially lower for sarcopenia at 9%, and slightly higher for sarcopenic-obesity with 12% being classified within this category. Aside from the possibility of variability in testing measurements due to conflicting methodologies, the differences in sarcopenia prevalence may be explained by the screening process in the current investigation and the recruitment of healthy volunteers, while the inconsistency in the obesity percentages may be tied to sociological factors, including geographical regions, or a historical effect with a general increase in obesity prevalence between the time of the Baumgartner publication and the present day (4, 7, 72, 92). More recently, and in support of the current findings, Waters et al. (109) examined older New Zealanders using similar DXA FAT% cut-off values (30% for men and 40% for women) and Baumgartner's RSMI cut-off values. The researchers reported 33% of men and 26% of women to be normal, 47% of men and 46% of women to be obese, 4% of men and 12% of women to be sarcopenic, and 16% of both men and women to be sarcopenic-obese (109).

Cross-validation of prediction equations for body fat percentage and relative skeletal muscle index

The prediction equations for FAT% and RSMI were devised using multiple regression and validated using double cross-validation. Heyward et al. (45) recommended this method and noted that smaller samples used to produce separate prediction equations with similar "predictive accuracy" may be combined to develop a single prediction equation. An additional avenue of validation, suggested by Sinning et al. and Lohman et al. (65, 93), includes the examination of the following principles: a) the actual and predicted mean values should be comparable; b) standard error of estimate (SEE) values should be minimal and in comparison to correlation coefficients are less likely to be impacted by differing means and sampling variability; c) total error, or the difference between the line of identity and the predicted values, as opposed to the error associated with regression characterized by SEE, should also be examined; and d) the standard deviations for the actual and predicted body composition values should be similar. Furthermore, total error and SEE values should be comparable, as this relationship represents a comparison between the regression line and the line of identity, and the actual values and constant error, or the difference between the actual and predicted values, should not be related (66). SEE and total error (TE) values for FAT% that are less than 4% are commonly considered acceptable (45, 64).

The results from the FAT% cross-validation analysis showed mean predicted values that were not significantly different from the actual values in both smaller samples. SEE values as percentages of mean actual FAT% were 12.9% and 10.6% for Sample A and Sample B, respectively. Total error values as percentages of mean actual FAT% were 13.0% for Sample A and 10.6% for Sample B. Both TE and SEE for the smaller samples, as well as the standard deviations between the actual and predicted FAT% values, were similar. The significant relationship between constant error and actual FAT% may provide some doubt with regard to the validity of the final prediction equation derived from the overall group.

The results from the RSMI cross-validation analysis showed mean predicted values that were not significantly different from the actual values in both smaller samples. SEE values as percentages of mean actual RSMI were 8.8% and 7.8% for Sample A and Sample B, respectively. Total error values as percentages of mean actual RSMI were 8.8% for Sample A and 7.8% for Sample B. Both total error and SEE for the smaller samples, as well as the standard deviations between the actual and predicted RSMI values, were similar. The significant relationship between constant error and actual RSMI may provide some doubt with regard to the validity of the final prediction equation derived from the overall group.

Body fat percentage and relative skeletal muscle index prediction equations

The final prediction equation for FAT% resulted in an SEE of 3.9937% and an adjusted R^2 value of 0.741. Likewise, Baumgartner et al. (8) developed a FAT% equation using anthropometric variables and DXA data in 199 elderly men and women with an SEE of 3.94% and an R^2 value of 0.79. Cross-validation of 50 subjects from within this sample yielded an SEE of 4.05% and an R^2 value of 0.82. The y-intercept of the regression line between the predicted and actual FAT% values was not significantly different from zero and slope was not different than 1.0. Furthermore, cross-validation with an independent sample of 401 elderly men and women produced an SEE of 4.42% and an R^2 value of 0.76. The researchers did note that when the equation was compared to the independent sample, the slope of the regression line was greater than 1.0 and FAT% might be underestimated in individuals with higher FAT% values (8). Additionally, Gallagher et al. (33) developed a prediction equation for DXA FAT% with an SEE of 4.31% and R^2 value of 0.81 which incorporated variables for age, sex, BMI, and race. This prediction equation was reported to produce higher FAT% in men and older individuals when compared to actual DXA values.

In the current study, the slope of the regression line between the observed and predicted FAT% values was not significantly different from 1.0 and the y-intercept was not different from zero (Figure 7). The use of the Bland-Altman plots with the current FAT% equation showed very low constant error (<0.0001) with 100 of the 107 data points (93%) falling within the limits of agreement (±7.72%) (Figure 8). However, a systematic bias was revealed with a regression slope for the difference between and the mean of the predicted and observed values that was significantly less than zero (Figure 8). This systematic bias can be interpreted as an underestimation of FAT% in individuals with higher FAT% values and an overestimation in individuals with lower FAT% values. Additionally, this finding is in line with the previously mentioned significant relationship between constant error and the actual FAT% values.

The final RSMI prediction equation in the current investigation resulted in an SEE of 0.5771 $kg \cdot m^{-2}$ and an adjusted R^2 value of 0.841. Sanada et al. (88) developed a series of prediction equations for RSMI from DXA values and anthropometric variables in men (and women between the ages of 18 and 85 years old. Following stepwise regression analysis, the researchers found significant partial correlations for BMI (partial R^2=0.548) and waist circumference (partial R^2=0.548) in men (age>40 years; n=81), and BMI (partial R^2=0.230), waist circumference (partial R^2=0.023), and handgrip strength (partial R^2=0.160) in women (age>40 years; n=201). The BMI and handgrip strength partial R^2 values are similar to those calculated in the current investigation. Sanada et al. (88) used multiple regression with this same group to examine RSMI prediction using BMI, waist circumference, and age in men, and BMI, handgrip strength, and waist circumference in women. Depending on the variables included, SEE values ranged from 0.35 $kg \cdot m^{-2}$ to 0.40 $kg \cdot m^{-2}$ for men and 0.14 $kg \cdot m^{-2}$ to 0.17 $kg \cdot m^{-2}$ for women. The reported R^2 values ranged 0.56 to 0.68 for men and

0.45 to 0.57 for women. The prediction equations using all three of the aforementioned variables were cross-validated in a separate group (age > 40 years; 221 men; 862 women) and the R^2 values, indicating a significant association between the measured and predicted RSMI values, were 0.733 for men and 0.605 for women.

In the current study, the slope of the regression line between the observed and predicted RSMI values was not significantly different from 1.0 and the y-intercept was not different from zero (Figure 9). The use of the Bland-Altman plots with the RSMI equation revealed very low constant error (<0.0001) with 101 of the 107 data points (94%) falling within the limits of agreement ($\pm 1.12\ \text{kg}\cdot\text{m}^{-2}$) (Figure 10). A systematic bias was shown with a regression slope for the difference between and the mean of the predicted and observed RSMI values that was significantly less than zero (Figure 10). This systematic bias can be interpreted as an underestimation of RSMI in individuals with higher RSMI values and an overestimation in individuals with lower RSMI values. As with FAT%, this finding is in line with the previously mentioned significant relationship between constant error and the actual RSMI values.

The differences between the observed and predicted prevalence values for classification as normal, obese, sarcopenic, and sarcopenic-obese were also compared. In the overall group (Figure 13), the major divergences appear to have occurred in the classification of sarcopenia and sarcopenic obesity. The prevalence of sarcopenia from predicted values was 16% versus 9% from the DXA values, while only 2% were predicted to be classified as sarcopenic-obese compared to 12% from DXA. This same conflict in classification appeared when the group was split by sex. Interestingly, the prevalence values for the normal classification tended to remain similar, while the obesity classification was slightly different for the men, women, and overall group. The prediction equations for RSMI and FAT% appear to be valid, albeit with some systematic bias towards overestimation or underestimation in individuals with fringe values. A comparison between the prevalence for DXA and predicted values shows that categorization may be affected with more individuals being classified as sarcopenic as opposed to sarcopenic-obese following RSMI and FAT% prediction. Furthermore, it appears that more individuals are classified as obese using the predicted values than those for DXA.

Isoperformance curves for body fat percentage and relative skeletal muscle index

Obesity isoperformance curves were developed from the FAT% prediction equations which represent FAT% values of 27% in men and 38% in women. Overweight isoperformance curves were developed which represent the obesity values minus the SEE from the FAT% prediction equation. These lines are arbitrary, but are useful in accounting for some of the inherent error introduced by the prediction equation. In this case, the SEE can be interpreted as a z-score (103) and the overweight isoperformance curve would account for an additional 34% of the prediction error from the FAT% prediction equation. For the purpose of the overweight isoperformance curve, 34% of the individuals who may have been incorrectly classified as non-obese would be considered overweight. Baumgartner's (7) original obesity cut-off points were the median values for the sample and because isoperformance curves are a function of the selected classification markers, the overweight classification could easily be selected as the adjacent quartile or 10th percentile. These values would provide another method of defining the overweight classification, but would not address any of the prediction error. For further comparison, Gallagher et al. (33) suggested FAT% for overweight and obesity as 25% and 31%, respectively in men and 38% and 43%, respectively in women. These values were based on four-compartment estimates in white men and women over the age of 60 years which corresponded to BMIs of greater than 25 $kg \cdot m^{-2}$ for overweight classification and 30 $kg \cdot m^{-2}$ for obesity classification.

When comparing the men, women, and overall group, the predicted prevalence values differ with respect to the normal, overweight, and obese classifications. In men, 6% are classified as normal and 67% are considered obese, and in women, 19% fall in the normal category and 45% in the obese category. The classification of overweight in men and women are comparable at 28% and 36%, respectively. The overall group presented 12% of individuals as normal, 32% as overweight, and 56% as obese. As previously stated, the cut-off standards for obesity were the median FAT% values from a group of elderly men and women, so having half of the overall group fall within this category could be expected. Using DXA FAT% measured in New Zealanders between the ages of 55 and 93 years, Waters et al. (109) reported 63% of men and 62% of women as obese, FAT% greater than 40% and 30%, respectively. Furthermore, Gomez-Cabello et al (38), using FAT% estimates from bioelectrical impedance analysis categorized by the Gallagher et al. (33) guidelines, determined 26.6% of men and 40.9% of women as obese with 58.7% of men and 43.1% of women as overweight.

Sarcopenia isoperformance curves were developed from the RSMI prediction equations, which represent RSMI values of 7.26 kg·m^{-2} for men and 5.45 kg·m^{-2} for women. Pre-sarcopenia isoperformance curves were developed which represent the sarcopenia values minus the SEE from the RSMI prediction equation. As discussed with the overweight isoperformance curves, the pre-sarcopenia curves are used to account for the variability produced by the prediction model. Baumgartner's (7) sarcopenia cut-off values are equal to two standard deviations below the young adult mean. Another viable option for pre-sarcopenia would be one standard deviation below the young adult mean as suggested by Sanada et al. (88). Other methods of sarcopenia classifications include the examination of skeletal muscle index from bioelectrical impedance analysis by percentiles or by the association with physical disability (53, 70).

When comparing the men, women, and overall group, the predicted prevalence values differ with respect to the normal, pre-sarcopenia, and sarcopenia classifications. For the normal category, the prevalence was 72% of men, 19% of women, and 46% of the overall group. Twenty-eight percent of men were considered pre-sarcopenic (22%) or saropenic (6%) compared to 81% of the women (51% pre-sarcopenic and 30% sarcopenic). The overall group was categorized as 36% pre-sarcopenic and 18% sarcopenic. Sanada et al. (88) reported sarcopenia prevalence values from DXA RSMI for Japanese men and women over the age of 40 years as being 1.7% in men and in 2.7% women. Pre-sarcopenia prevalence values were higher (28.8% in men and 20.7% in women), and the differences when compared to the current study, aside from race, might be explained by the broader age span of their sample. Tanko et al.

(97) showed prevalence from DXA RSMI for healthy women over the age of 70 years as 32.9% pre-sarcopenic and 12.3% sarcopenic. Using skeletal muscle index from bioelectrical impedance analysis in sample of elderly individuals over the age of 60 years (n=4,440), Janssen et al. (53) estimated 9.4% of women and 11.2% of men to be categorized as sarcopenic, and 21.9% of women and 53.1% of men to be pre-sarcopenic. The data for Janssen et al. (53) study was taken from the National Health and Nutrition Examination Survey (NHANES) in the United States and the divergence from the current study could be explained by the inclusion of primarily healthy individuals with a specific limitation for BMI.

Determination of appropriate interventions from isoperformance curves

Specific interventions may be selected in order to address an elderly individual's body composition. The isoperformance curves developed to demarcate between non-sarcopenic and sarcopenic, as well as non-obese, and obese individuals, can be used to differentiate individuals into four distinct categories of body composition. The categories of body composition include: normal, obese, sarcopenic, and sarcopenic obese. Handgrip strength and BMI values can be used to systematically organize individuals into these categories of body composition. The intersection of the sarcopenia and obesity isoperformance curves provides the division of the graphical display into quadrants (I-IV) (Figure 22 and Figure 23). Individuals with data points in the resultant quadrants (I-IV) can be split into intervention groups.

Individuals in Quadrant I may be characterized as having "normal" body composition and have predicted RSMI values greater than established sarcopenia cutoff values and predicted FAT% values less than established cutoff values. These individuals may not require specialized interventions or advanced methods may be appropriate. Quadrant II represents “obese” individuals with predicted RSMI values greater than established sarcopenia cutoff values and predicted FAT% values greater than established cutoff values. These individuals may be targeted for weight-loss interventions aimed at decreasing BMI. Quadrant III represents “sarcopenic” individuals with predicted RSMI values less than established sarcopenia cutoff values and predicted FAT% values less than established cutoff values. These individuals may be targeted for muscle-building interventions aimed at increasing strength. Quadrant IV represents “sarcopenic-obsese” individuals with predicted RSMI values less than established sarcopenia cutoff values and predicted FAT% values greater than established cutoff values. These individuals may be targeted for combined muscle-building and weight-loss interventions aimed at increasing strength and decreasing BMI.

The primary interventions related to body composition phenotypes, regardless of age, fall into two categories, either nutrition-related or exercise-related, and most often require alterations in both in order to achieve the necessary changes. The current discussion has primarily focused on the body composition phenotypes of sarcopenia and obesity, which are the emphasis of most exercise training or dietary programs in the elderly. However, aging individuals in the normal category should also be concerned with dietary habits and physical activity. Fortunately, many of the normal individuals may have already benefited from a heightened level of fitness throughout their lifespan. Koster et al. (60) recently reported that individuals in higher fitness categories at age 70 years lost significantly less lean mass over a seven-year follow up period than individuals in the low fitness categories. It was also noted that the more fit individuals had higher strength values, but declined at a similar rate as the less fit individuals. Additionally, the most fit individuals had significantly lower body fat percentages at baseline than those in the lower fitness categories (60). Therefore, higher levels of fitness are encouraged throughout the lifespan in order to maximum lean mass during the process of aging and to minimize the possibility of elderly obesity. The American College of Sports Medicine/American Heart Association recommends physical activity for all older adults that includes components of aerobic, strength, flexibility, and balance exercise (18, 69).

The American Society for Nutrition and the NAASO, The Obesity Society suggest that elderly obese individuals reduce daily energy intake between 500 and 750 kilocalories without dropping below 800 kilocalories per day (100). Further recommendations include maintaining protein intake greater than one gram per kilogram of body weight per day and supplementing the diet with calcium and vitamin D (100). Using these guidelines along with combined aerobic and resistance training, Villareal et al. (102) examined the effects of each intervention separately and together on obese older adults over the course of one year. The researchers found that diet and exercise collectively improved physical function to a greater degree than either intervention on its own. Exercise alone did not decrease body weight, whereas diet and diet/exercise promoted reductions of 10% and 9%, respectively. Assuming a relative maintenance in height over the course of the interventions, the weight loss would have resulted in BMI decreases of 3.5 $kg \cdot m^{-2}$ in the diet group and 3.2 $kg \cdot m^{-2}$ in the diet/exercise group. The diet/exercise group produced similar fat mass losses to the diet group, while only the exercise group increased lean body mass. Interestingly, thigh muscle measured from magnetic resonance imaging decreased in response to both diet and diet/exercise, while thigh fat decreased more in the diet/exercise group than the diet only group. Of additional consideration, there was a relationship between the exercise intervention and an increase in the occurrence of musculoskeletal injuries (102). The results from this study and the current recommendations suggest that exercise alone should not be utilized when addressing obesity in elderly individuals and that a dietary component with energy restriction may be necessary.

In order to address sarcopenia, through increases in muscle mass, strength, and power, consistent and progressive resistance training programs of moderate or greater intensity are recommended (85). Training intensity and training volume, defined together as training dosage, have been identified as being related to strength and lean body mass, respectively (78). Another factor in resistance training design, frequency of training, may be particularly useful in the elderly due to possible limitations with regard to training volume in a single workout (77). Loenneke et al. (63) recently suggested the use of blood flow occlusion and low-intensity resistance training for elderly people dealing with sarcopenia. Despite the variety of training programs currently in use, Peterson et al. (79, 80) conducted meta-analyses showing resistance training to be particularly effective in improving muscular strength and lean body mass in adults over the age of 50 years old. Particularly relevant to the current study, resistance training has been shown to improve handgrip strength in elderly men and women (83, 98). When considering dietary habits and sarcopenia in the elderly, Paddon-Jones et al. (75) advocate ingestion of 25 to 30 grams of high quality protein per meal in order to maximize muscle protein synthesis. Furthermore, the researchers suggested that the amino acid, leucine, may be crucial in maintaining muscle during the later stages of life. Campbell (15) also presented information from several studies highlighting improvements in strength and body composition in elderly individuals who consumed at the least the recommended daily allowance for protein (0.8 grams per kilogram of body weight) in conjunction with resistance training. Adequate protein consumption has been shown to be positively related with the preservation of appendicular lean mass, the primary component of RSMI, in older women undergoing caloric restriction and exercise (12). Additionally, creatine supplementation prior to and following resistance training has also been shown to increase strength and fat-free mass in elderly men and women (16). Interventions for individuals classified as sarcopenic should primarily focus on an appropriately-designed resistance training program with changes in dietary intake, specifically protein, used to enhance adaptations in lean body mass and muscular strength.

The goals of interventions designed to impact sarcopenic obesity are two-fold and as described separately when discussing obesity and sarcopenia, their aims may be conflicting. Weight loss with energy restriction has shown to greatly effect muscle mass with estimated decrements in body weight composed of 75% fat-free mass and 25% fat mass (6, 100, 101). Weinheimer et al. (110) conducted a systematic review of 52 studies examining the effects of only energy restriction (36 groups), only exercise (16 groups), or a combination of energy restriction and exercise (36 groups) on body composition in older adults. A majority of the exercise interventions included in this review were aerobic-based. Most of the energy restriction (5-10% loss: 61%; ≥10% loss: 36%) and energy restriction plus exercise groups (5-10% loss: 69%; ≥10% loss: 28%) lost more than 5% of body weight during the interventions, while 94% of the exercise only groups lost less than 5% of body weight. At least 20% of the energy restriction and energy restriction plus exercise groups lost more than 5% fat-free mass, while 31% of the exercise only groups maintained fat-free mass throughout the interventions. The amount of body weight lost as fat-free mass was greater than or equal to 25% in 50% of the energy restriction only groups compared to 22% and 30% in the energy restriction plus exercise and exercise groups, respectively (110). Therefore, exercise is an important component in the maintenance of fat-free mass during energy restricted weight loss in older adults. The authors noted that 60% of the energy restriction studies examined utilized daily caloric intakes of greater than 1,300 kilocalories with less than a 500 kilocalorie decrease per day, whereas the rest of the studies followed more aggressive guidelines similar to those outlined in the obesity discussion above. Interestingly, Wang et al. (107) reported improvements in muscle strength despite a significant reduction in both body weight and (8.1%) and lean body mass (2.9%) over the course of a six-month mixed aerobic and strength training program with energy restriction. The researchers also showed that muscle quality increased during the intervention and demonstrated a significant inverse relationship between this measure and fat mass, which decreased almost 14%. The classification of sarcopenic obesity in elderly individuals presents a unique set of issues. An altered version of the dietary recommendations for the obese category with slightly less energy restriction and a combination of the exercise recommendations for the sarcopenic and obese categories, considering both aerobic and strength training, should be considered for individuals in the sarcopenic-obese category.

Conclusion

The process of aging causes a wide variety of physiological changes that can manifest in the form of differing phenotypes of body composition. The assessment of body composition is a task that varies in complexity as well as in the resources needed to complete an adequate evaluation. DXA-based criterion values of FAT% and RSMI have been used to determine clinical guidelines for the categorization of body composition phenotypes. During the current investigation, the field-based measurements of BMI and handgrip strength coupled with sex were used to develop prediction equations for the DXA-based criterion values. Subsequently, isoperformance curves were utilized in order to incorporate the clinical guidelines developed for FAT% and RSMI with the field-based measures that are regularly obtained in a community setting. The appropriate selection of interventions can be a formidable task when considering the specialized needs of elderly individuals categorized as normal, obese, sarcopenic, or sarcopenic-obese. The final goal of this investigation was to produce easily understood charts that can be placed in fitness centers or community clinics to be used by personal trainers, nutrition specialists, and/or health professionals. The charts could be used in the classification of individuals into these categories in an inexpensive and non-invasive manner. Future research should be undertaken that enhances the current findings by increasing the sample size and producing tailored interventions for each body composition category.

The isoperformance concept may also be used in any situation where a tradeoff in methodologies, systems, or theories can be exploited. Particular opportunities may lie in examining the relationship of strength versus power, aerobic versus anaerobic energy systems, or resistance versus endurance training in various special populations and settings.

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APPENDIX A

TABLES

Table 1. Descriptive and anthropometric statistics for the study participants.

	Overall (n=107)		Male (n=54)			Female (n=53)	
	Mean	SD	Mean	SD		Mean	SD
Age (y)	72.6	± 6.0	72.5	± 5.7		72.7	± 6.4
Height (m)	1.69	± 0.09	1.76	± 0.06	*	1.62	± 0.06
Weight (kg)	73.5	± 14.7	83.1	± 11.0	*	63.7	± 11.2
Body Mass Index (kg·m^{-2})	25.6	± 3.4	26.9	± 2.7	*	24.3	± 3.5
Handgrip Strength (kg)	30.1	± 11.8	39.7	± 8.2	*	20.3	± 4.6

* Significantly different by sex ($p<0.05$)

Table 2. Body composition values from dual-energy X-ray absorptiometry (DXA).

	Overall (n=107)		Male (n=54)		Female (n=53)	
	Mean	SD	Mean	SD	Mean	SD
Bone Mineral Content (kg)	2.8	± 0.7	3.4	± 0.4	2.2	± 0.7
Fat Mass (kg)	24.8	± 7.5	24.6	± 6.9	25.0	± 8.1
Body Fat Percentage	33.9	± 7.8	29.1	± 5.5 *	38.8	± 6.8
Lean Mass (kg)	45.8	± 11.1	55.5	± 6.0 *	35.9	± 4.4
Arms Lean Mass (kg)	5.2	± 1.8	6.8	± 1.0 *	3.6	± 0.5
Legs Lean Mass (kg)	15.0	± 4.2	18.5	± 2.6 *	11.4	± 1.7
Appendicular Lean Mass (kg)	20.2	± 5.9	25.3	± 3.4 *	15.0	± 2.1
Relative Skeletal Muscle Index ($kg \cdot m^{-2}$)	6.96	± 1.45	8.18	± 0.87 *	5.71	± 0.61

* Significantly different by sex ($p<0.05$)

Table 3. Pearson's correlation coefficients (r) for body mass index, handgrip strength, body fat percentage, and relative skeletal muscle index calculated from the Overall Group (n=107).

	BMI			GRIP			FAT%			RSMI		
	r		p-value	r		p-value	r		p-value	r		p-value
Body Mass Index (BMI)	--			0.438	†	<0.001	0.305	†	0.001	0.575	†	<0.001
Handgrip Strength (GRIP)	0.438	†	<0.001	--			-0.514	†	<0.001	0.851	†	<0.001
Body Fat Percentage (FAT%)	0.305	†	0.001	-0.514	†	<0.001	--			-0.559	†	<0.001
Relative Skeletal Muscle Index (RSMI)	0.575	†	<0.001	0.851	†	<0.001	-0.559	†	<0.001	--		

* $p<0.05$; † $p<0.01$

Table 4. Pearson's correlation coefficients (r) for body mass index, handgrip strength, body fat percentage, and relative skeletal muscle index calculated from Men (n=54).

	BMI		GRIP		FAT%		RSMI	
	r	p-value	r	p-value	r	p-value	r	p-value
Body Mass Index (BMI)	--		0.338 *	0.012	0.700 †	<0.001	0.527 †	<0.001
Handgrip Strength (GRIP)	0.338 *	0.012	--		0.048	0.730	0.510 †	<0.001
Body Fat Percentage (FAT%)	0.700 †	<0.001	0.048	0.730	--		0.161	0.246
Relative Skeletal Muscle Index (RSMI)	0.527 †	<0.001	0.510 †	<0.001	0.161	0.246	--	

* $p<0.05$; † $p<0.01$

Table 5. Pearson's correlation coefficients (r) for body mass index, handgrip strength, body fat percentage, and relative skeletal muscle index calculated from Women (n=53).

	BMI		**GRIP**		**FAT%**		**RSMI**	
	r	p-value	r	p-value	r	p-value	r	p-value
Body Mass Index (BMI)	--		0.177	0.204	0.772 †	<0.001	0.594 †	<0.001
Handgrip Strength (GRIP)	0.177	0.204	--		-0.055	0.698	0.452 †	0.001
Body Fat Percentage (FAT%)	0.772 †	<0.001	-0.055	0.698	--		0.051	0.718
Relative Skeletal Muscle Index (RSMI)	0.594 †	<0.001	0.452 †	0.001	0.051	0.718	--	

* $p<0.05$; † $p<0.01$

Table 6. Pearson's correlation coefficients (r) for age and body mass index, handgrip strength, body fat percentage, and relative skeletal muscle index.

	Overall (n=107)			Male (n=54)			Female (n=53)		
	r		p-value	r		p-value	r		p-value
Body Mass Index	-0.218	*	0.024	-0.222		0.107	-0.234		0.092
Handgrip Strength	-0.212	*	0.028	-0.382	†	0.004	-0.360	†	0.008
Body Fat Percentage	-0.046		0.638	-0.059		0.671	-0.082		0.561
Relative Skeletal Muscle Index	-0.216	*	0.026	-0.394	†	0.003	-0.410	†	0.002

* $p<0.05$; † $p<0.01$

Table 7. Linear regression equation validation values for body fat percentage (FAT%).

	Observed Mean ± SD (%)	Predicted Mean ± SD (%)	SEE (%)	TE (%)	CE (%)	P-value	intercept	slope
Sample A (n=54) **Equation 2**	33.35 ± 8.45	33.03 ± 8.40	4.30	4.368	0.321	0.595	4.63	0.870
Sample B (n=53) **Equation 1**	34.35 ± 7.14	34.49 ± 5.44	3.65	3.652	-0.136	0.790	-4.71	1.133

SD=standard deviation; SEE=standard error of estimate; TE= total error; CE= constant error.

Table 8. Linear regression equation validation values for relative skeletal muscle index (RSMI).

	Observed Mean ± SD ($kg \cdot m^{-2}$)	Predicted Mean ± SD ($kg \cdot m^{-2}$)	SEE ($kg \cdot m^{-2}$)	TE ($kg \cdot m^{-2}$)	CE ($kg \cdot m^{-2}$)	p-value	intercept	slope
Sample A (n=54) **Equation 2**	7.04 ± 1.35	7.07 ± 1.33	0.621	0.622	-0.025	0.773	0.63	0.907
Sample B (n=53) **Equation 1**	6.90 ± 1.53	6.88 ± 1.35	0.540	0.536	0.016	0.827	-0.39	1.059

SD=standard deviation; SEE=standard error of estimate; TE= total error; CE= constant error.

Table 9. Results of multiple regression analyses for body fat percentage and relative skeletal muscle index.

	Body Fat Percentage				Relative Skeletal Muscle Index			
	Mean	SE	Partial R^2	p-value	Mean	SE	Partial R^2	p-value
Intercept	-5.550	± 3.716		0.138	3.653	± 0.537		<0.001
Sex	10.226	± 1.374	0.349	<0.001	-1.363	± 0.199	0.314	<0.001
Handgrip Strength	-0.176	± 0.061	0.076	<0.001	0.043	± 0.009	0.192	<0.001
Body Mass Index	1.550	± 0.128	0.587	0.004	0.104	± 0.019	0.236	<0.001

SE = standard error

APPENDIX B

EQUATIONS

Equation 1. Linear regression equation for body fat percentage (FAT%) from Sample A (n=54).

$$Sample\ A\ (n = 54)$$

$$FAT\% = (8.694 \times Sex) + (1.585 \times BMI) + (-0.198 \times Grip) - 4.987$$

$$R^2 = 0.750; \mathrm{SEE} = 4.3536\%$$

Equation 2. Linear regression equation for body fat percentage (FAT%) from Sample B (n=53).

$$Sample\ B\ (n = 53)$$

$$FAT\% = (10.355 \times Sex) + (1.665 \times BMI) + (-0.234 \times Grip) - 6.984$$

$$R^2 = 0.755; \mathrm{SEE} = 3.6398\%$$

Equation 3. Linear regression equation for body fat percentage (FAT%) from the Overall Group (n=107).

$$Overall\ Group\ (n = 107)$$

$$FAT\% = (10.226 \times Sex) + (1.550 \times BMI) + (-0.176 \times Grip) - 5.550$$

$$Adjusted\ R^2 = 0.741; \mathrm{SEE} = 3.9937\%$$

Equation 4. Linear regression equation for relative skeletal muscle index (RSMI) from Sample A (n=54).

$$Sample\ A\ (n = 54)$$

$$RSMI = (-1.226 \times Sex) + (0.108 \times BMI) + (0.044 \times Grip) + 3.466$$

$$R^2 = 0.798; \mathrm{SEE} = 0.6265\ kg \cdot m^{-2}$$

Equation 5. Linear regression equation for relative skeletal muscle index (RSMI) from Sample B (n=53).

$$Sample\ B\ (n = 53)$$

$$RSMI = (-1.352 \times Sex) + (0.085 \times BMI) + (0.052 \times Grip) + 3.886$$

$$R^2 = 0.881; \mathrm{SEE} = 0.5437\ kg \cdot m^{-2}$$

Equation 6. Linear regression equation for relative skeletal muscle index (RSMI) from the Overall Group (n=107).

$$Overall\ Group\ (n = 107)$$

$$RSMI = (-1.363 \times Sex) + (0.104 \times BMI) + (0.043 \times Grip) + 3.653$$

$$Adjusted\ R^2 = 0.841; \mathrm{SEE} = 0.5771\ kg \cdot m^{-2}$$

Equation 7. Linear equation for body fat percentage isoperformance curves.

$$Grip = \frac{FAT\% - (10.226 \times Sex) - (1.550 \times BMI) + 5.550}{-0.176}$$

Equation 8. Linear equation for relative skeletal muscle index isoperformance curves.

$$Grip = \frac{RSMI - (-1.363 \times Sex) - (0.104 \times BMI) - 3.653}{0.043}$$

APPENDIX C

FIGURES

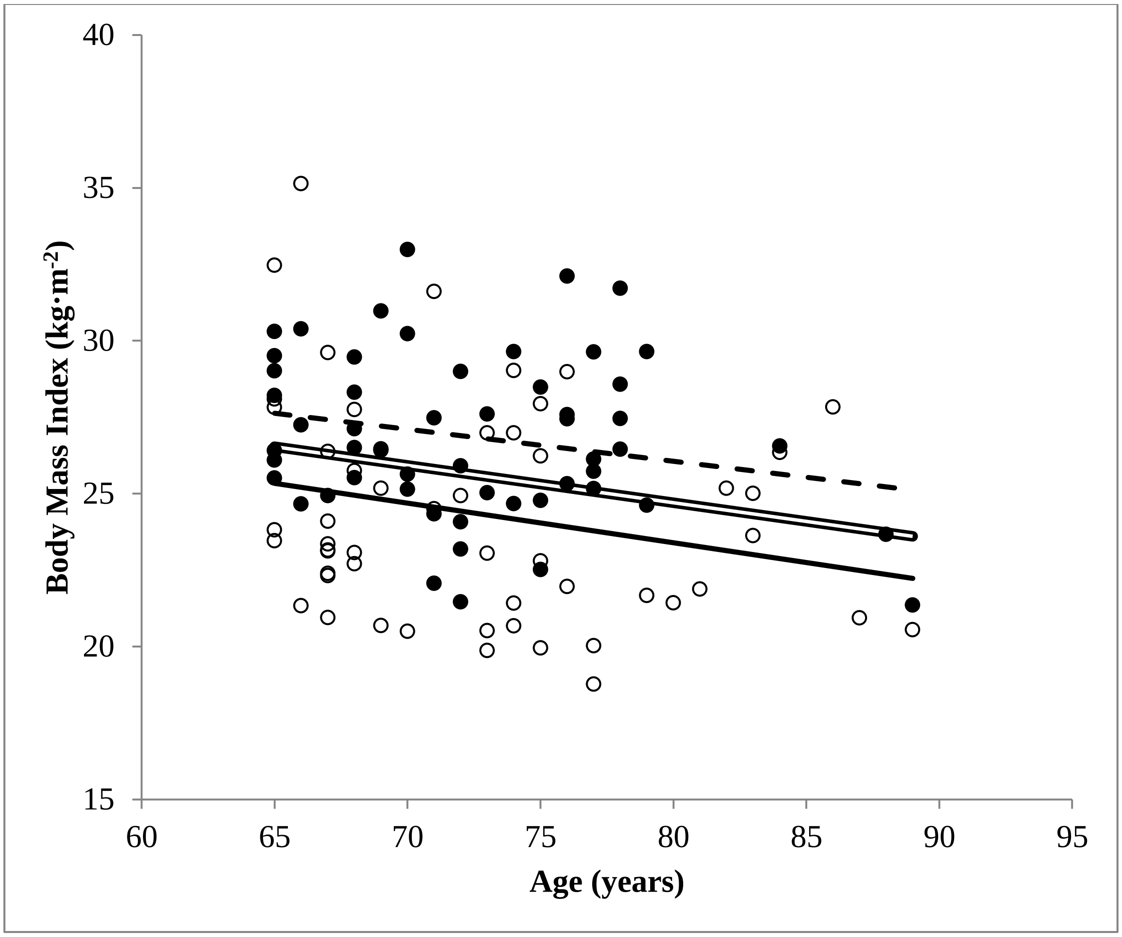


Figure 1. Cross-sectional scatterplot of age and body mass index values with closed circles indicating male participants and open circles indicating female participants. Linear regression for the overall group (compound line; y = -0.1218x + 34.452) indicated a slope coefficient significantly different than zero ($p<0.05$). The slope coefficients for men (solid line; y = -0.1294x + 33.745) and women (dashed line; y = -0.1048x + 34.446) were not significantly different than zero ($p>0.05$)

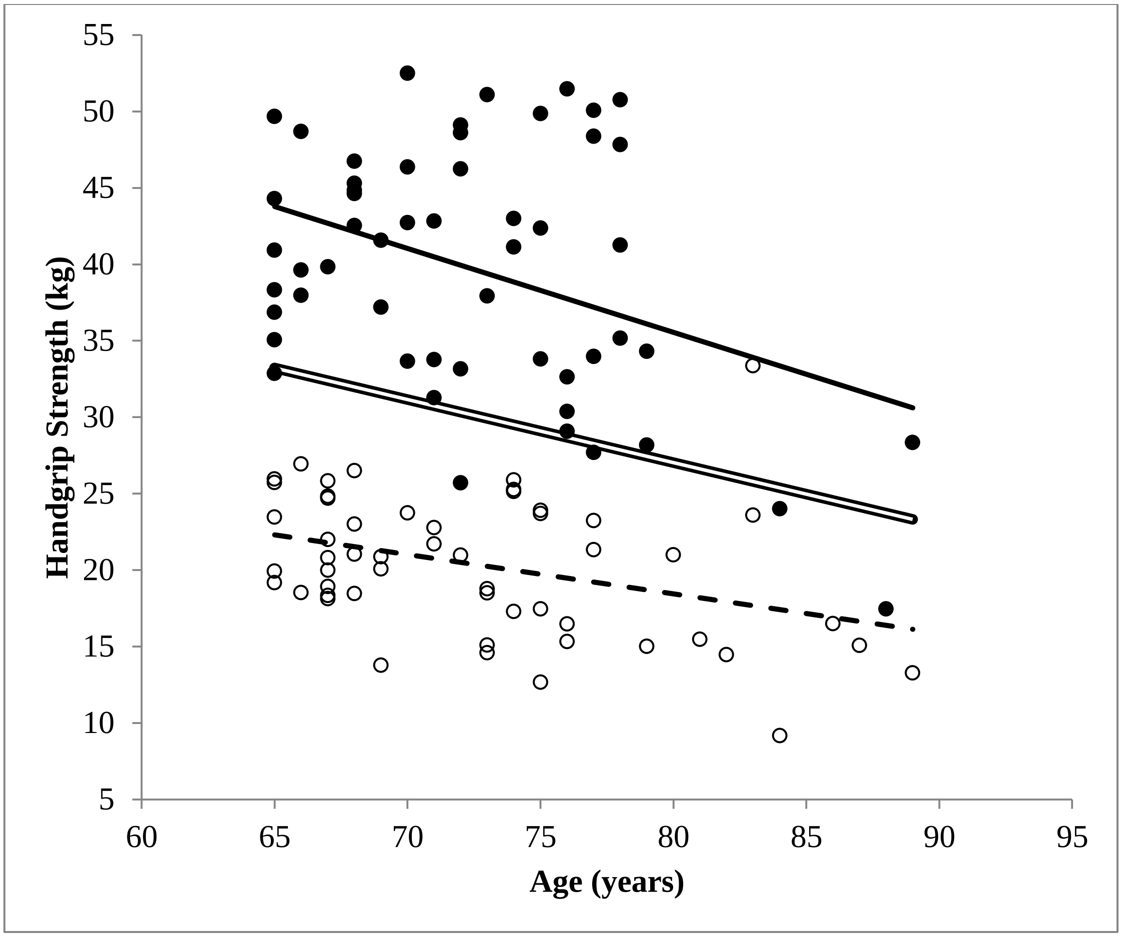


Figure 2. Cross-sectional scatterplot of age and handgrip strength values with closed circles indicating male participants and open circles indicating female participants. Linear regression for the overall group (compound line; y = -0.4128x + 60.05), men (solid line; y = -0.5483x + 79.42), and women (dashed line; y = -0.2569x + 39.003) indicated slope coefficients were significantly different than zero (p<0.05).

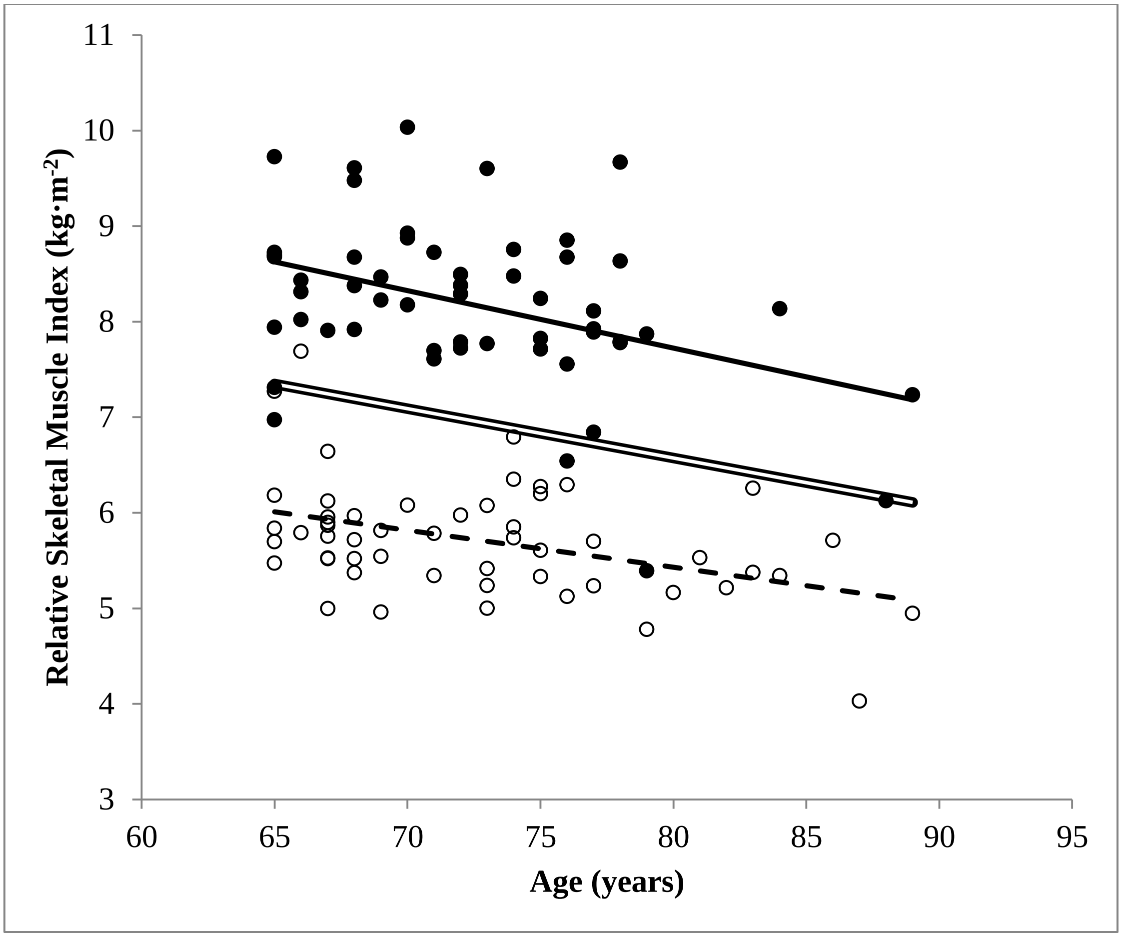


Figure 3. Cross-sectional scatterplot of age and relative skeletal muscle index values with closed circles indicating male participants and open circles indicating female participants. Linear regression for the overall group (compound line; y = -0.0516x + 10.704), men (solid line; y = -0.0602x + 12.539), and women (dashed line; y = -0.0388x + 8.5301) indicated slope coefficients were significantly different than zero ($p<0.05$).

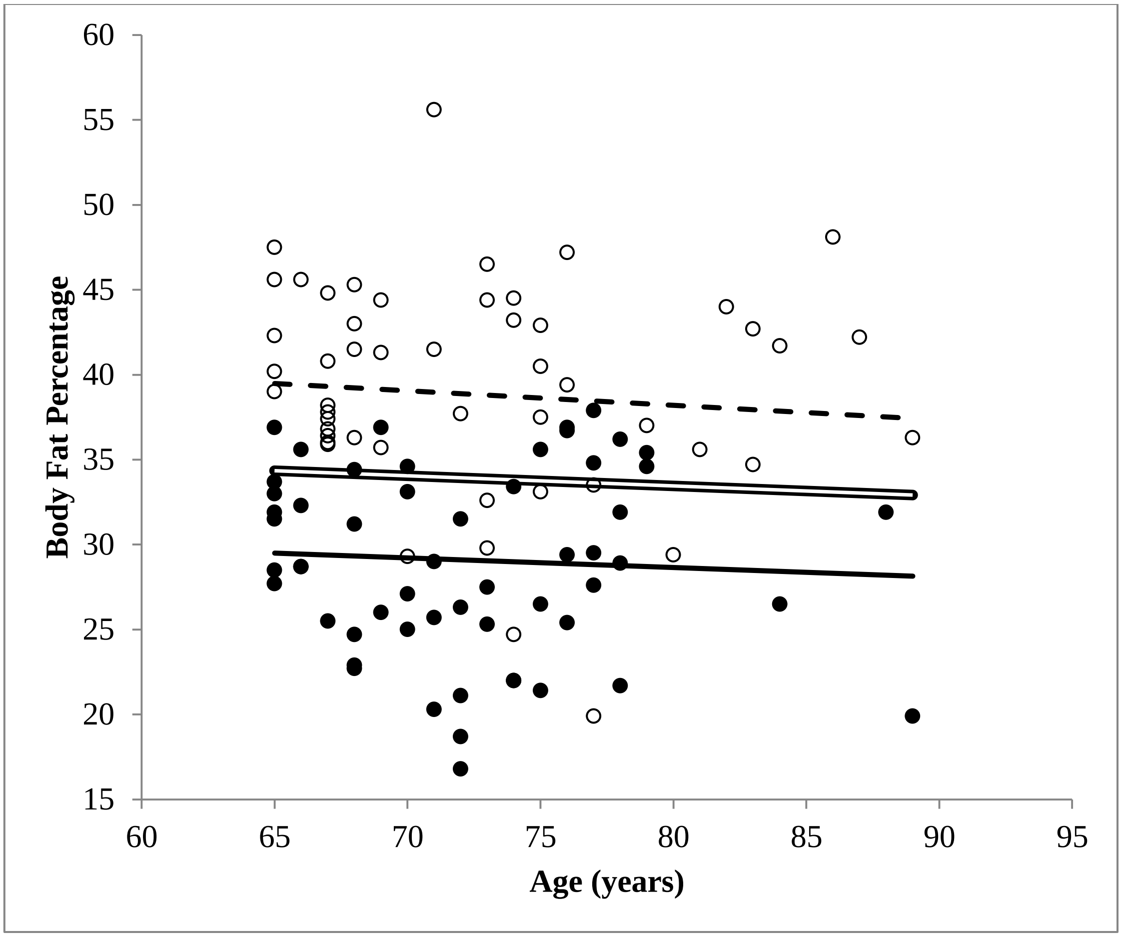


Figure 4. Cross-sectional scatterplot of age and handgrip strength values with closed circles indicating male participants and open circles indicating female participants. Linear regression for the overall group (compound line; y = -0.0598x + 38.247), men (solid line; y = -0.057x + 33.212), and women (dashed line; y = -0.086x + 45.082) indicated slope coefficients were not significantly different than zero (p>0.05).

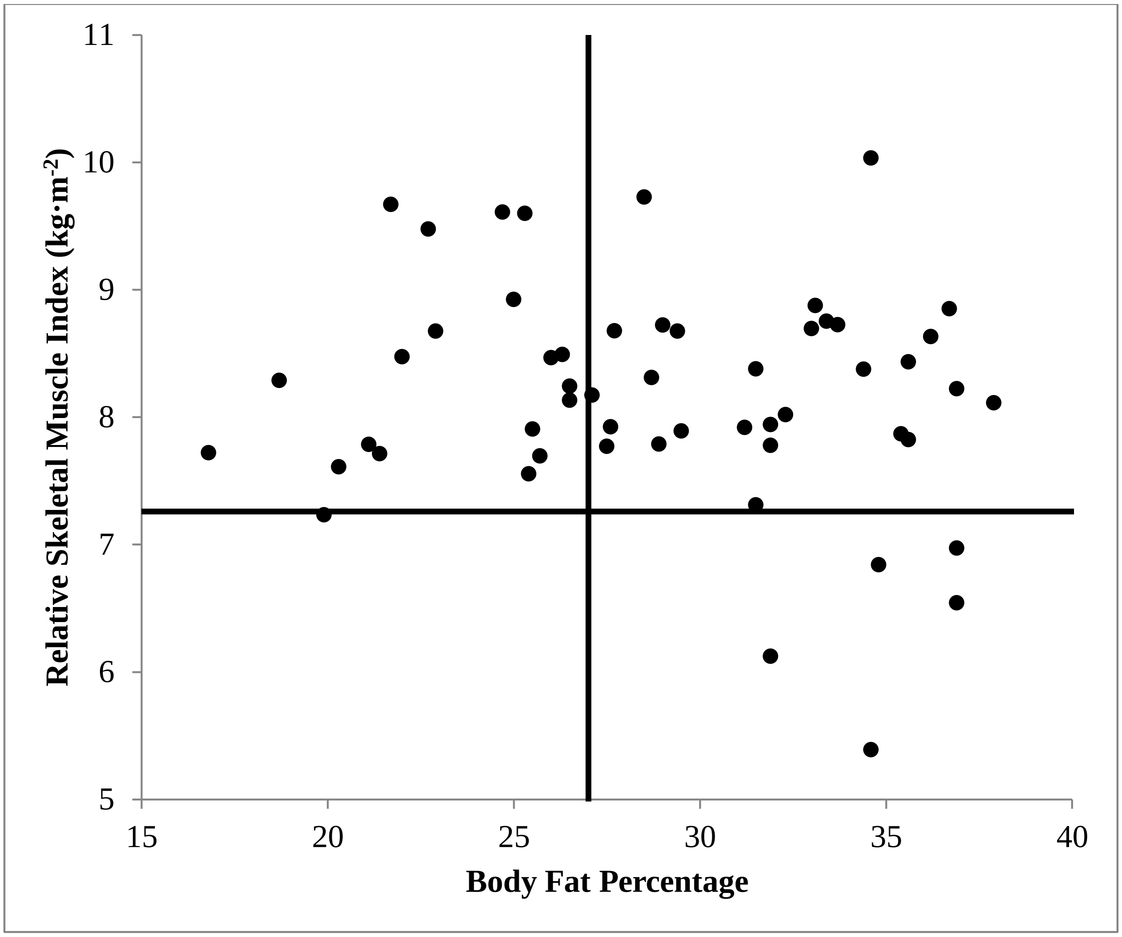


Figure 5. Comparison of individual relative skeletal muscle index and body fat percentage values for men as determined by dual energy X-ray absorptiometry with a horizontal line representing a sarcopenia cut-off value of 7.26 kg·m^{-2} and a vertical line representing an obesity cut-off value of 27%.

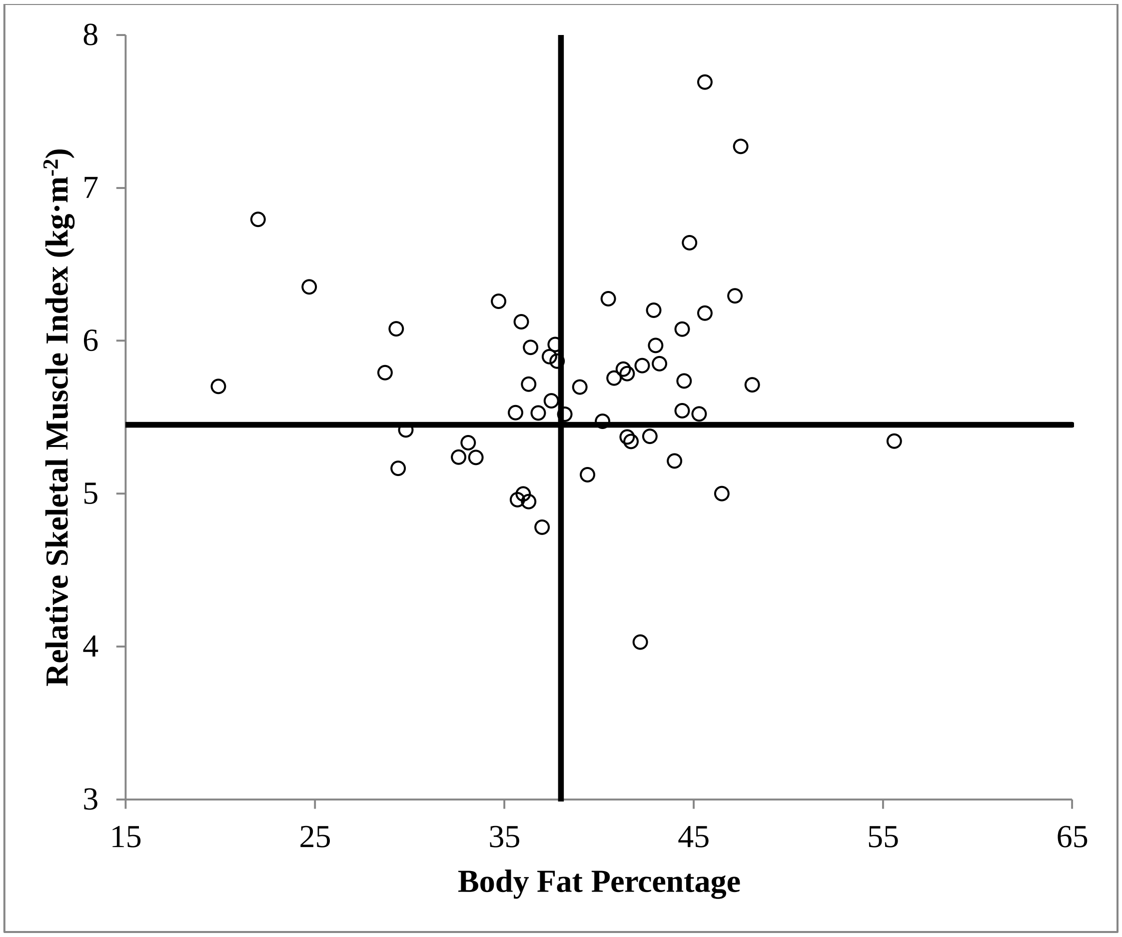


Figure 6. Comparison of individual relative skeletal muscle index and body fat percentage values for women as determined by dual energy X-ray absorptiometry with a horizontal line representing a sarcopenia cut-off value of 5.45 kg·m^{-2} and a vertical line representing an obesity cut-off value of 38%.

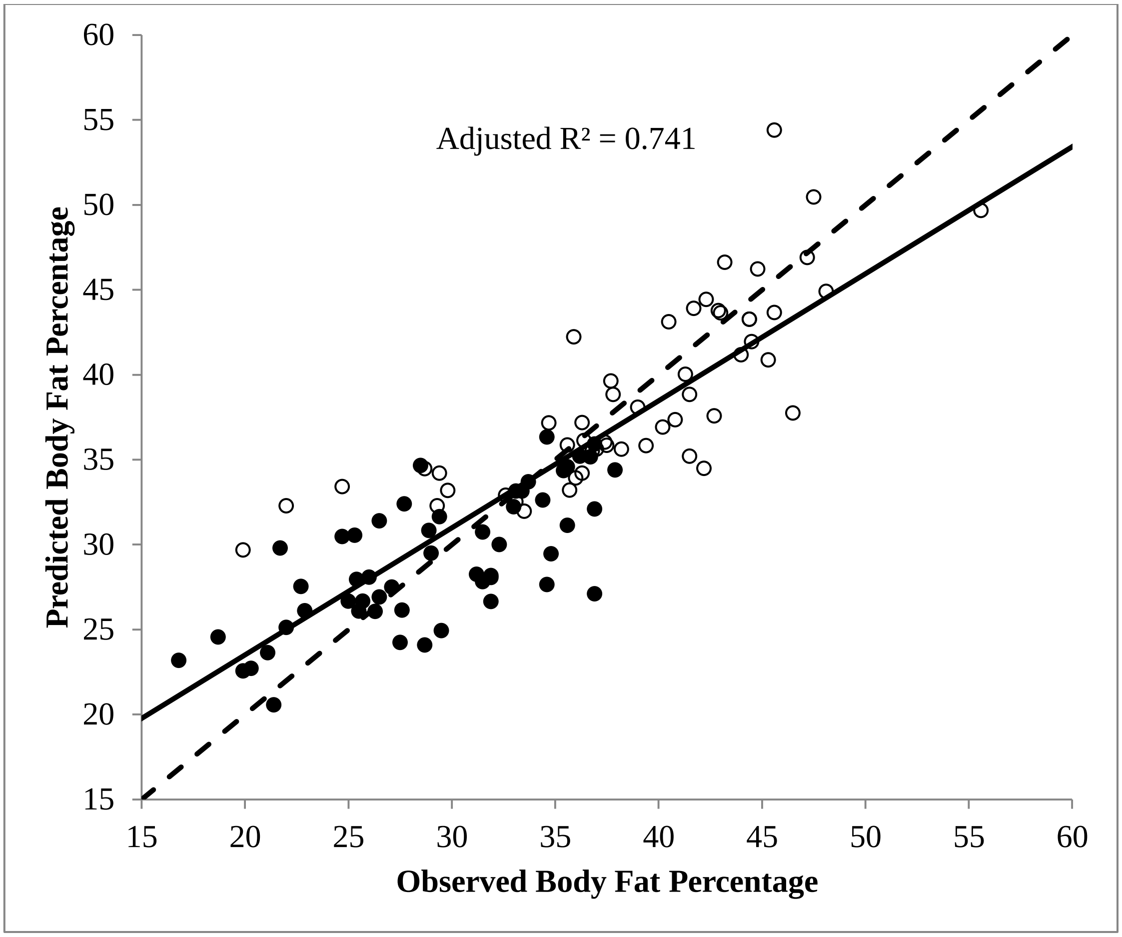


Figure 7. Scatterplot of observed and predicted body fat percentage values with closed circles indicating male participants and open circles indicating female participants. The solid line is the regression line and the dashed line is the line of identity.

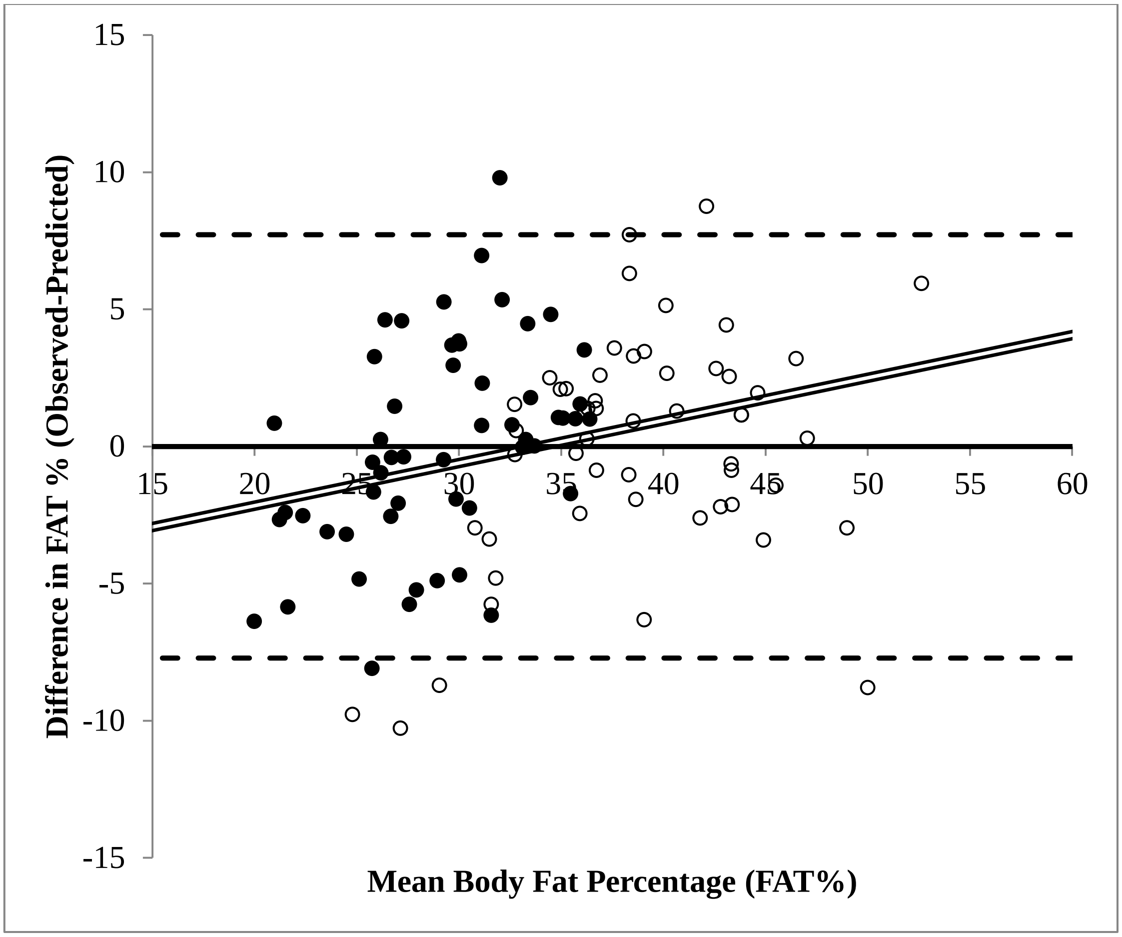


Figure 8. Bland-Altman plot with bias (solid line) ± 95% limits of agreement (dashed lines) comparing observed and predicted relative body fat percentage (FAT%) values with closed circles indicating male participants and open circles indicating female participants. Linear regression (compound line) indicated systematic bias and a slope significantly different from zero ($m=0.155$; $p<0.01$).

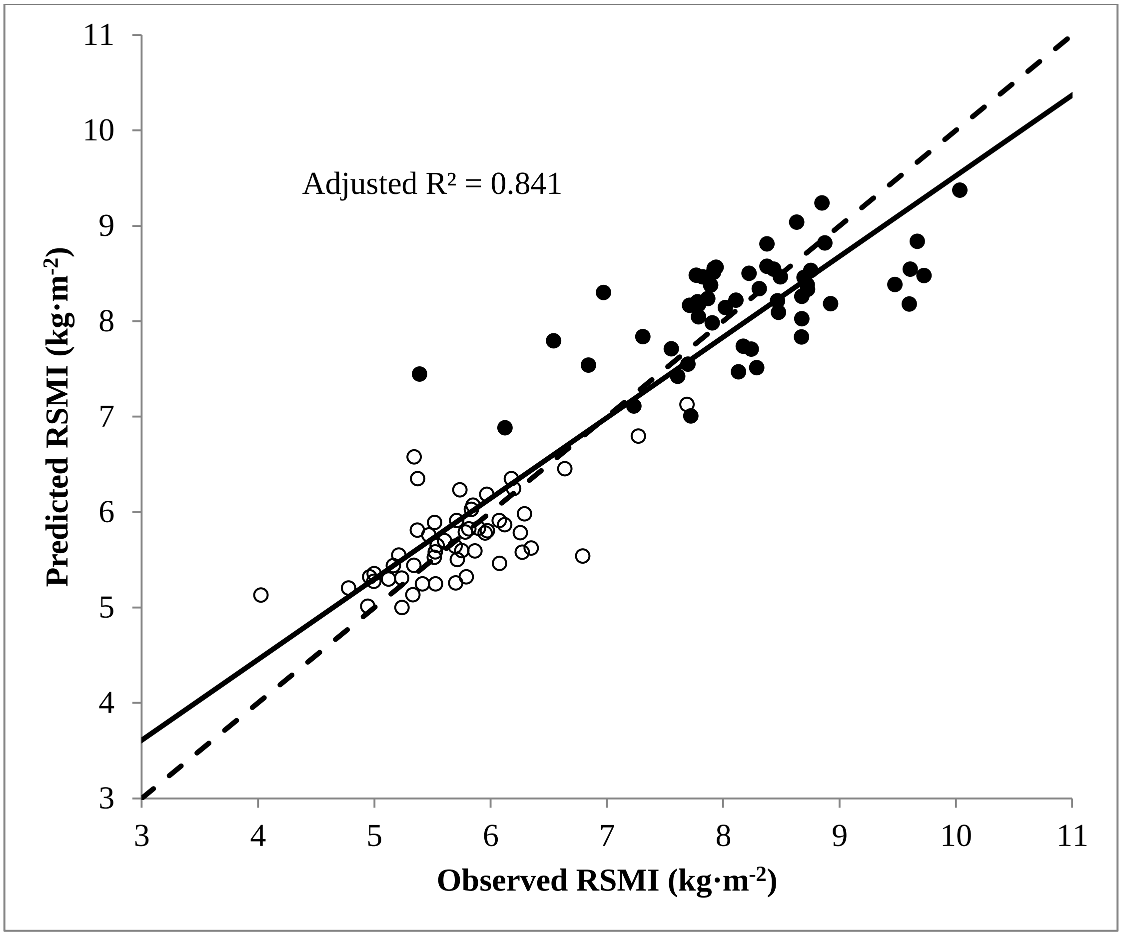


Figure 9. Scatterplot of observed and predicted relative skeletal muscle index (RSMI) values with closed circles indicating male participants and open circles indicating female participants. The solid line is the regression line and the dashed line is the line of identity.

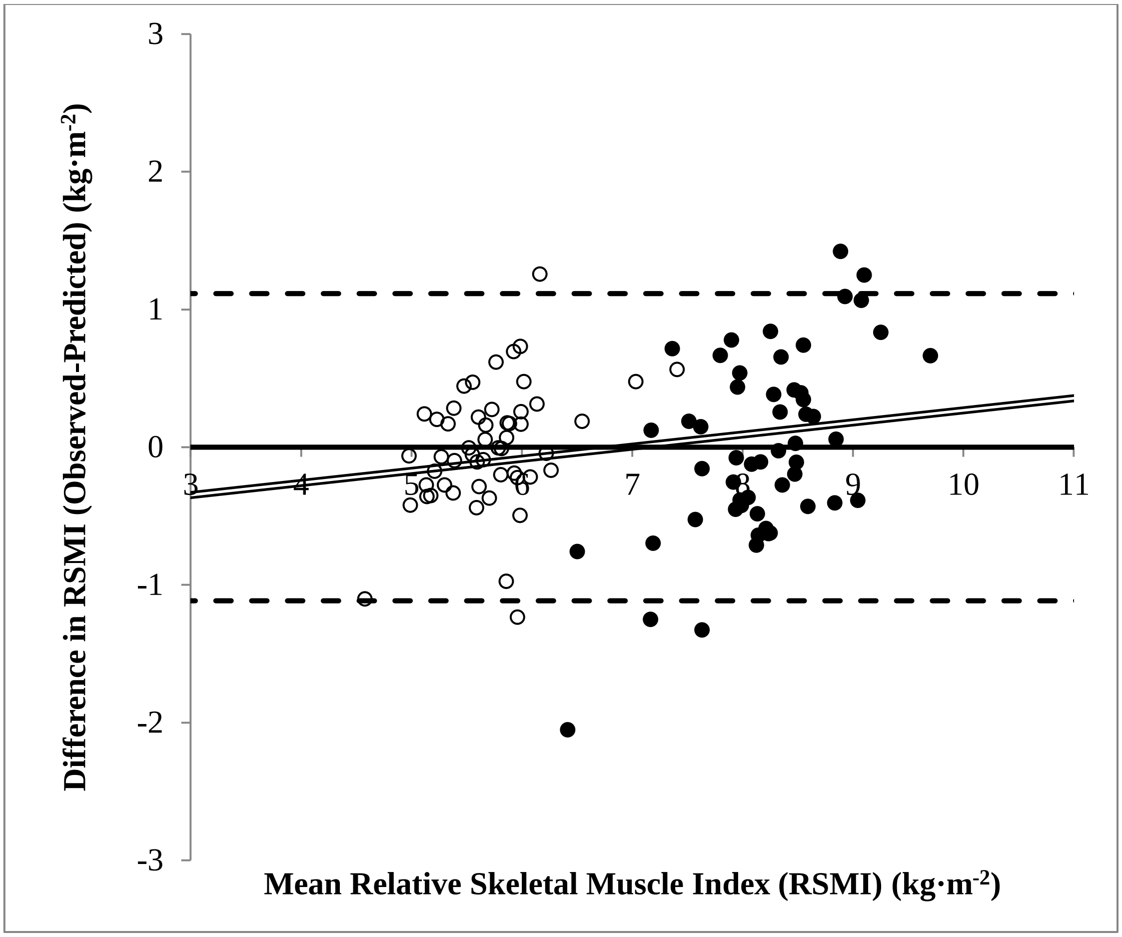


Figure 10. Bland-Altman plot with bias (solid line) ± 95% limits of agreement (dashed lines) comparing observed and predicted relative skeletal muscle index (RSMI) values with closed circles indicating male participants and open circles indicating female participants. Linear regression (compound line) indicated systematic bias and a slope significantly different from zero ($m=0.088$; $p<0.01$).

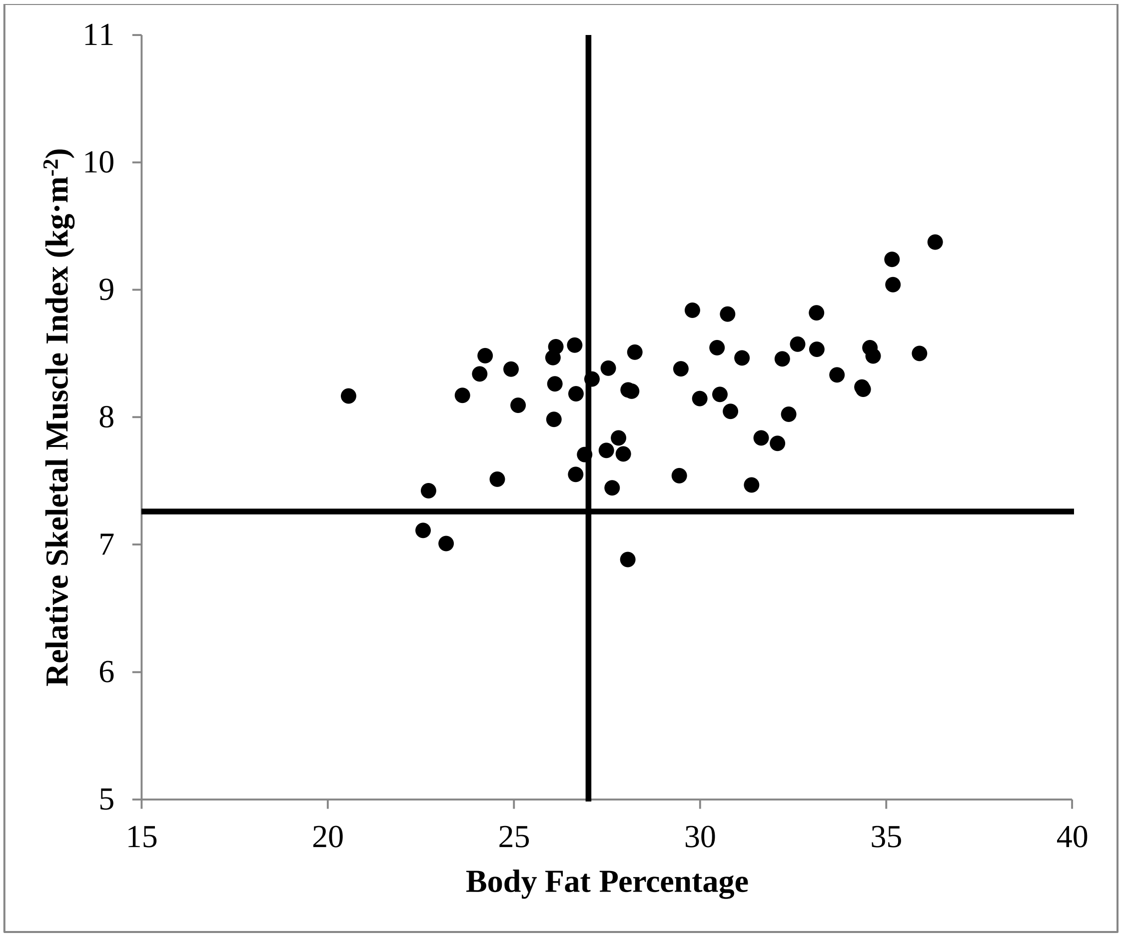


Figure 11. Comparison of predicted individual relative skeletal muscle index and body fat percentage values for men with a horizontal line representing a sarcopenia cut-off value of 7.26 kg·m^{-2} and a vertical line representing an obesity cut-off value of 27%.

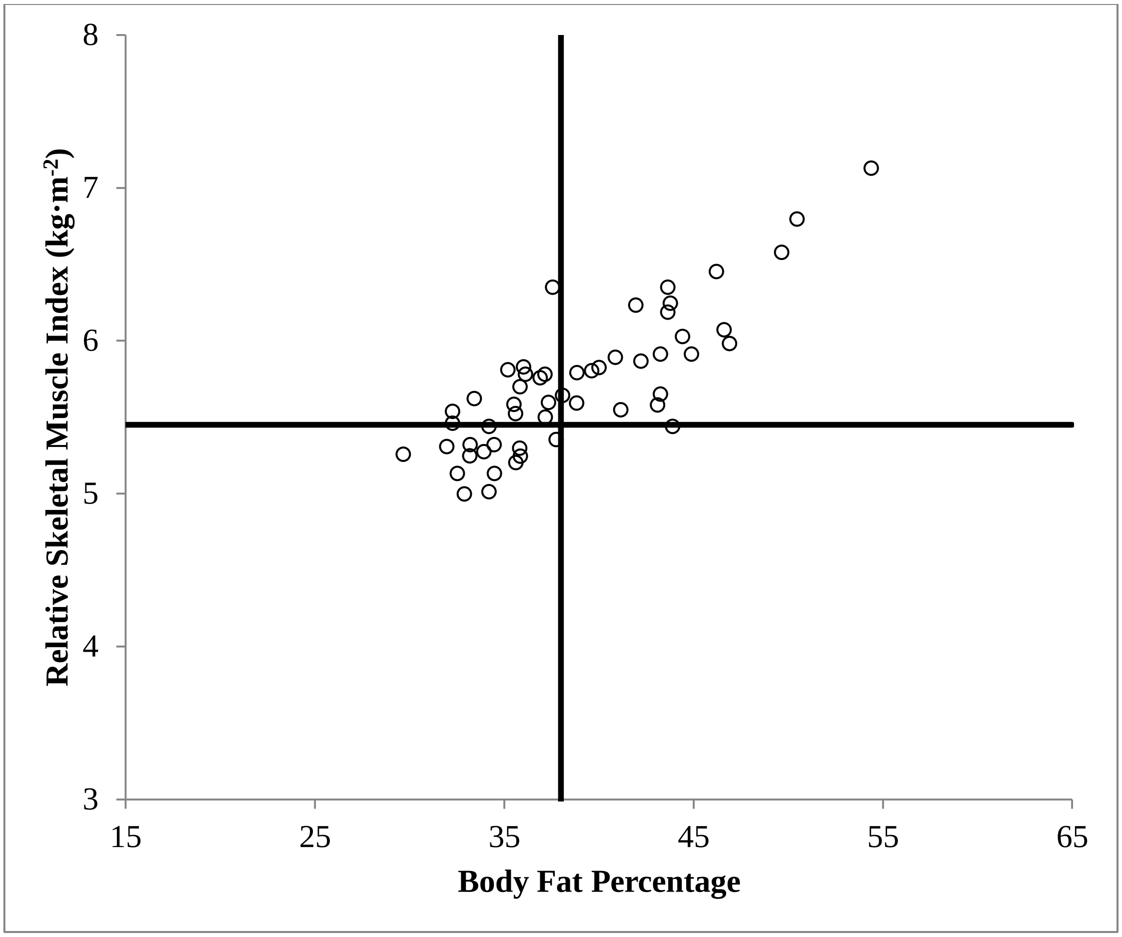


Figure 12. Comparison of predicted individual relative skeletal muscle index and body fat percentage values for women with a horizontal line representing a sarcopenia cut-off value of 5.45 kg·m^{-2} and a vertical line representing an obesity cut-off value of 38%.

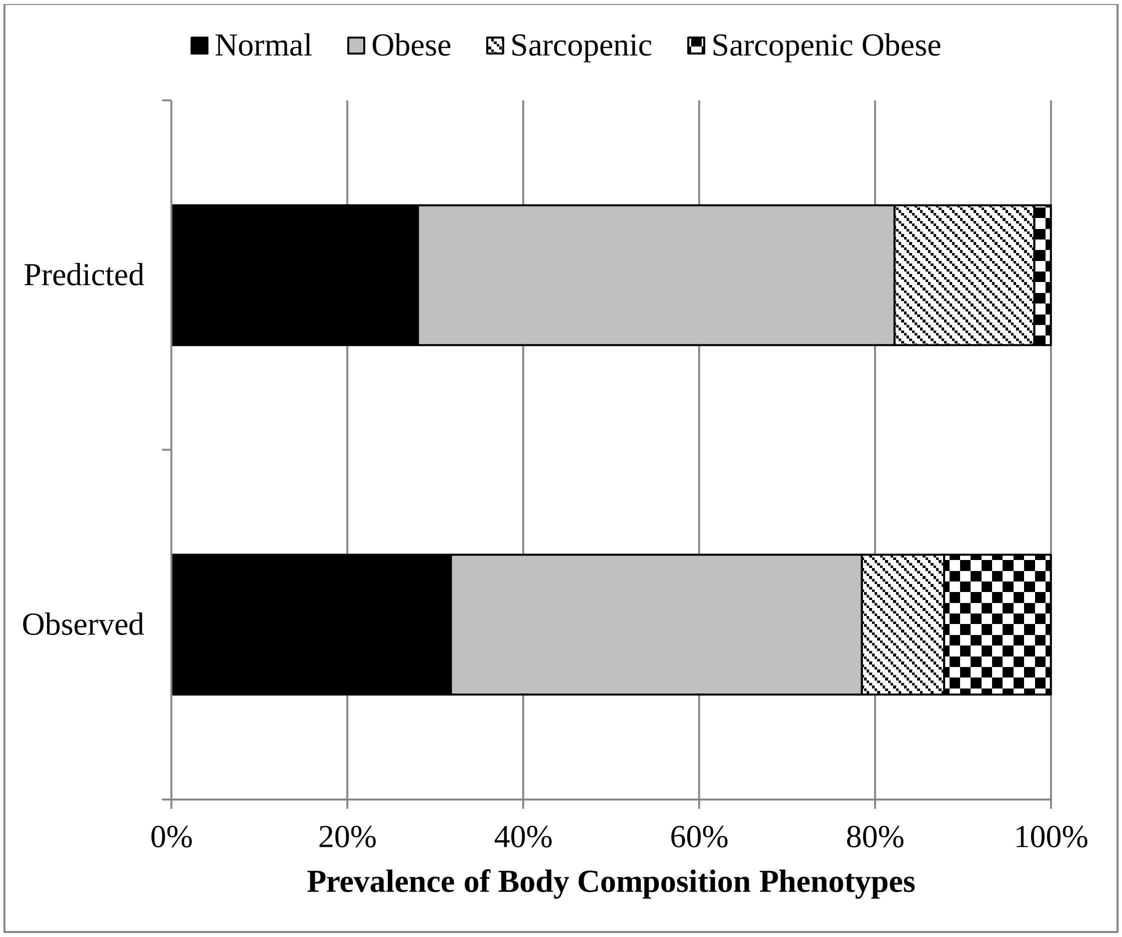


Figure 13. Observed and predicted prevalence values for categories of body composition phenotypes for the overall group (n=107).

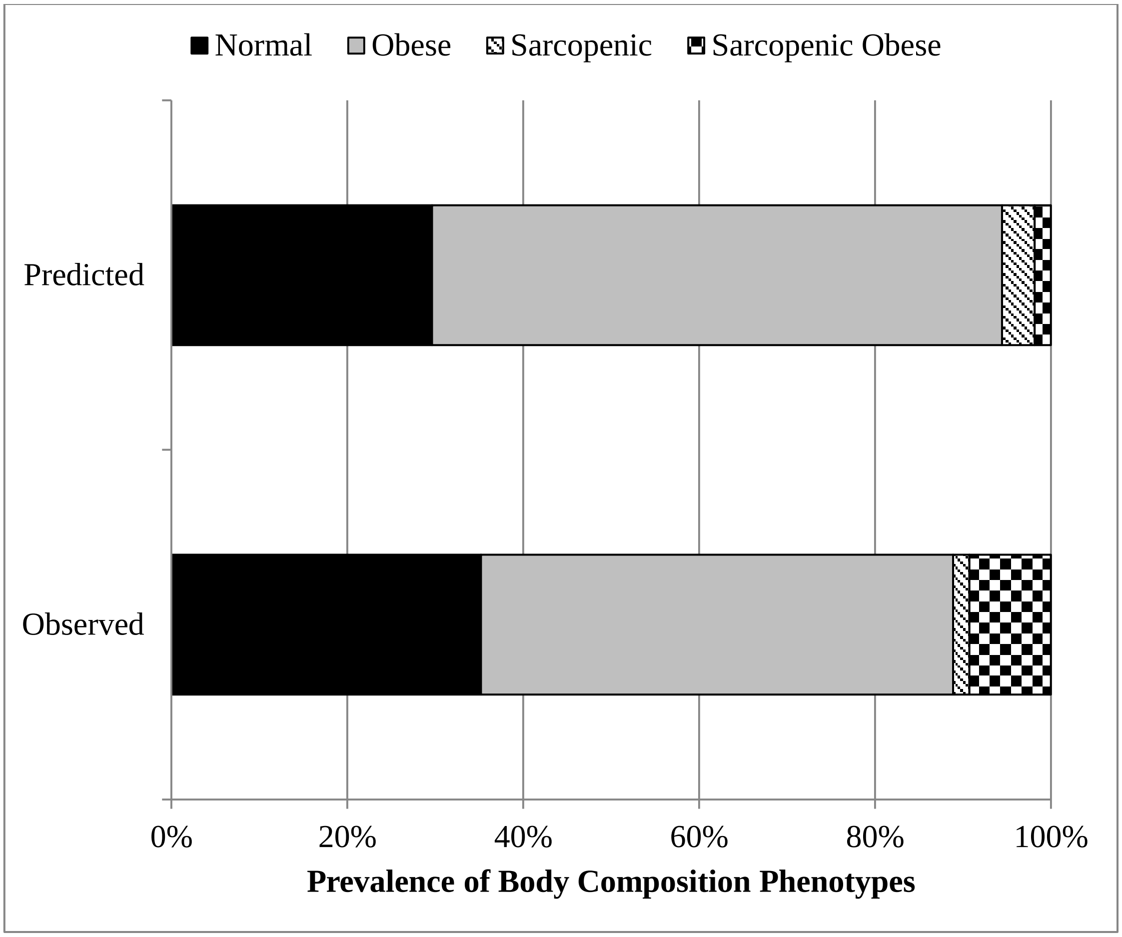


Figure 14. Observed and predicted prevalence values for categories of body composition phenotypes for men (n=54).

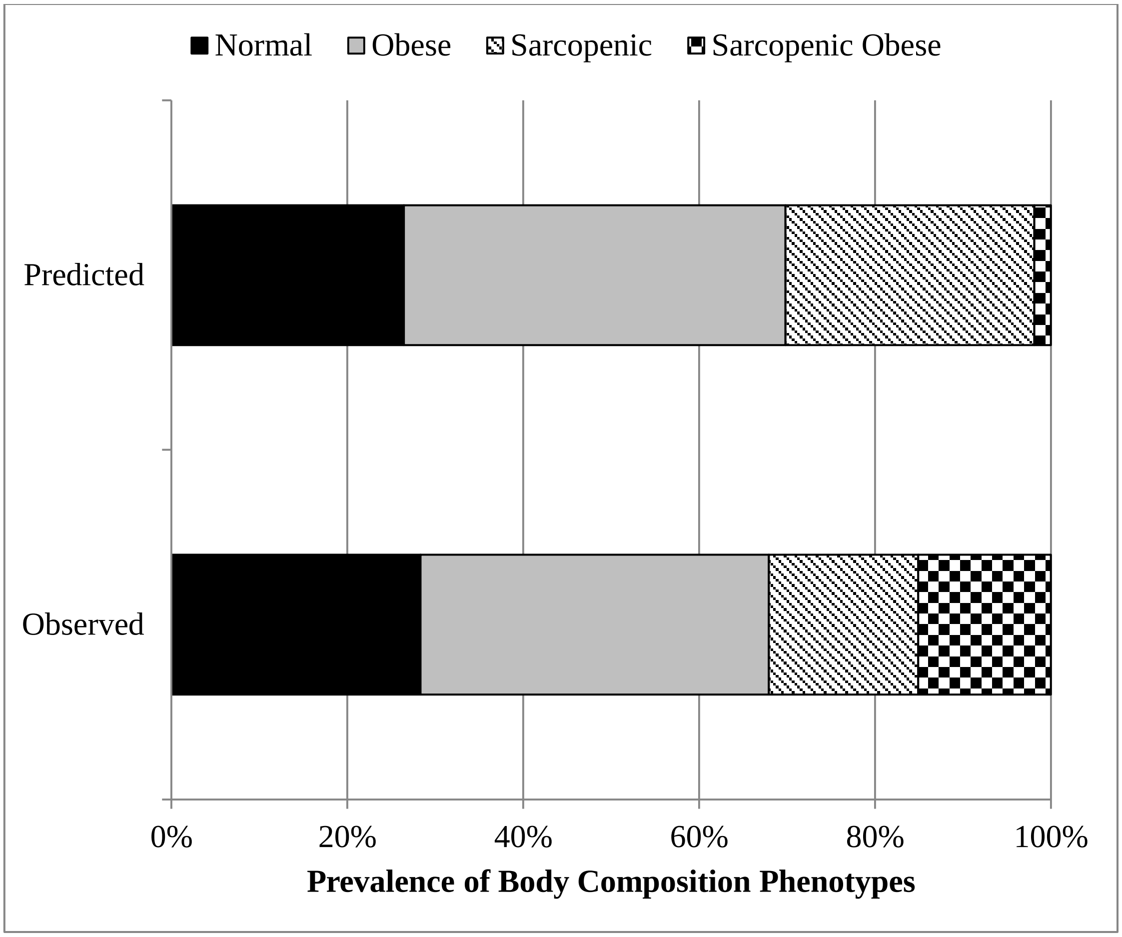


Figure 15. Observed and predicted prevalence values for categories of body composition phenotypes for women (n=53).

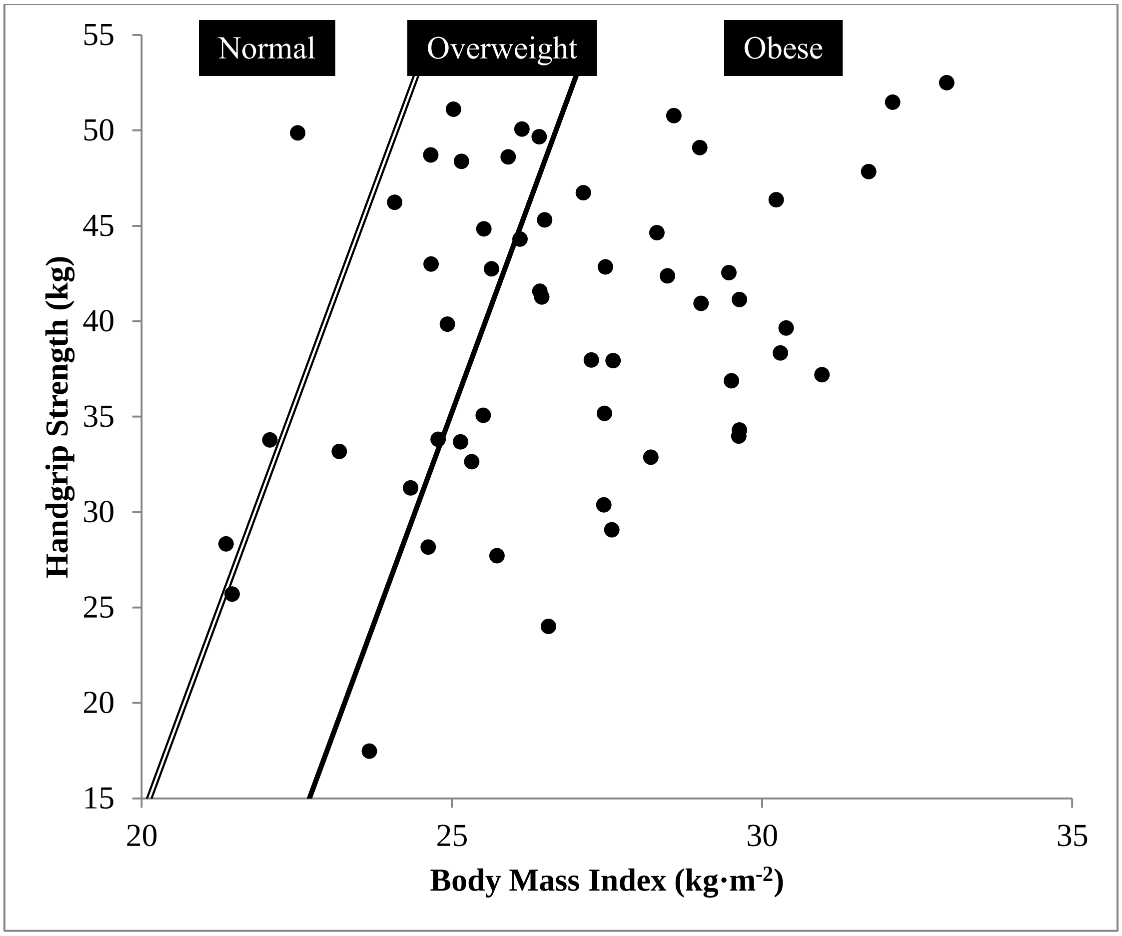


Figure 16. Comparison of individual body mass index and handgrip strength values for women with isoperformance curves representing a body fat percentage cut-off value of 27% (dashed line) and 23% (27% minus standard error of the estimate; compound dashed line).

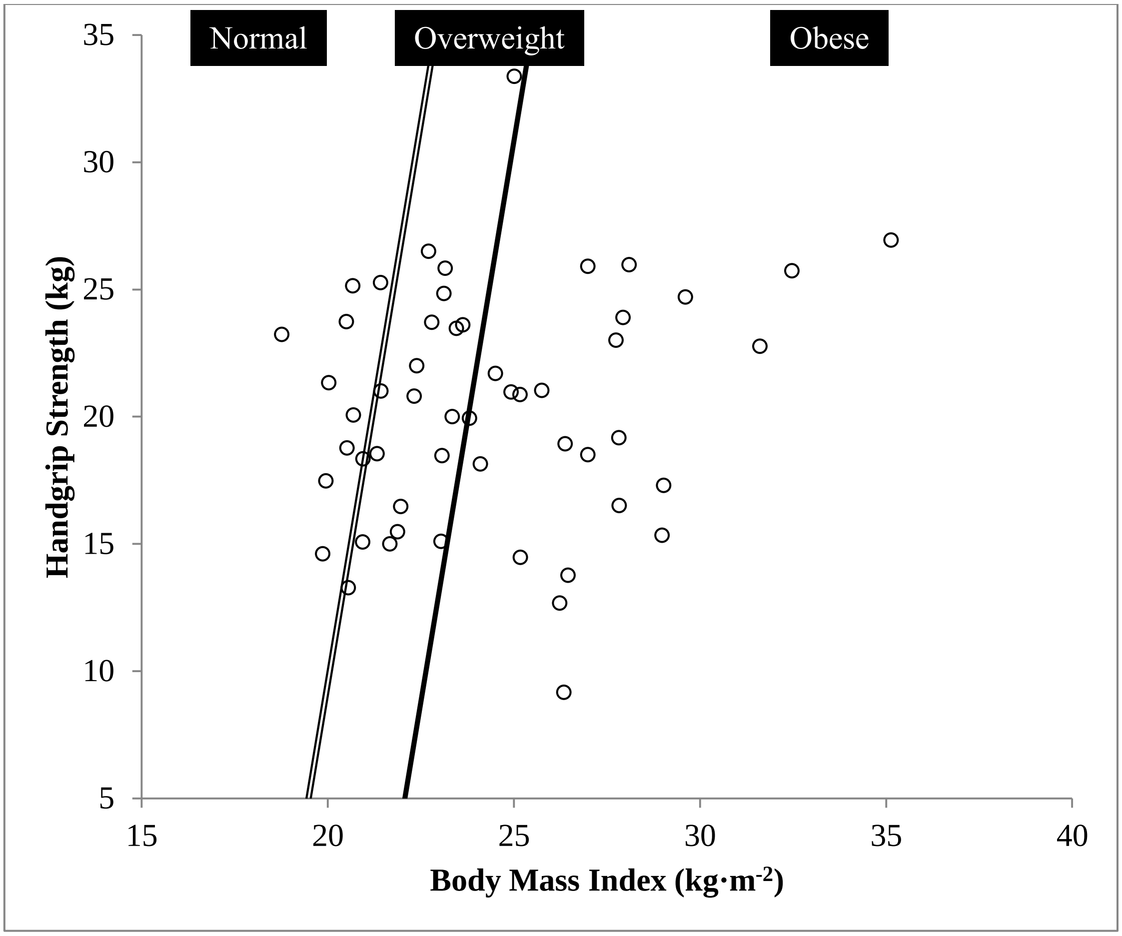


Figure 17. Comparison of individual body mass index and handgrip strength values for women with isoperformance curves representing a body fat percentage cut-off value of 38% (dashed line) and 34% (38% minus standard error of the estimate; compound dashed line).

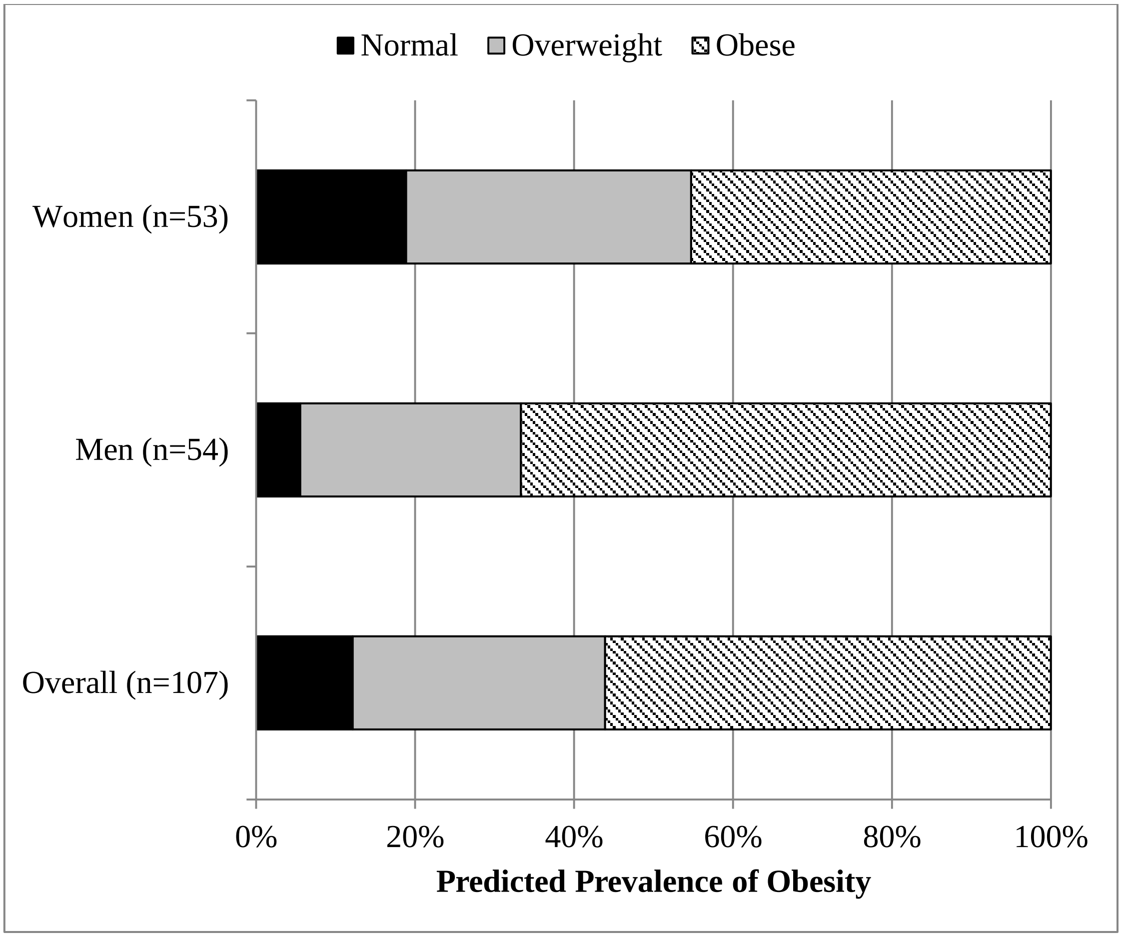


Figure 18. Prevalence values from body fat percentage prediction for normal adiposity, overweight, and obese individuals.

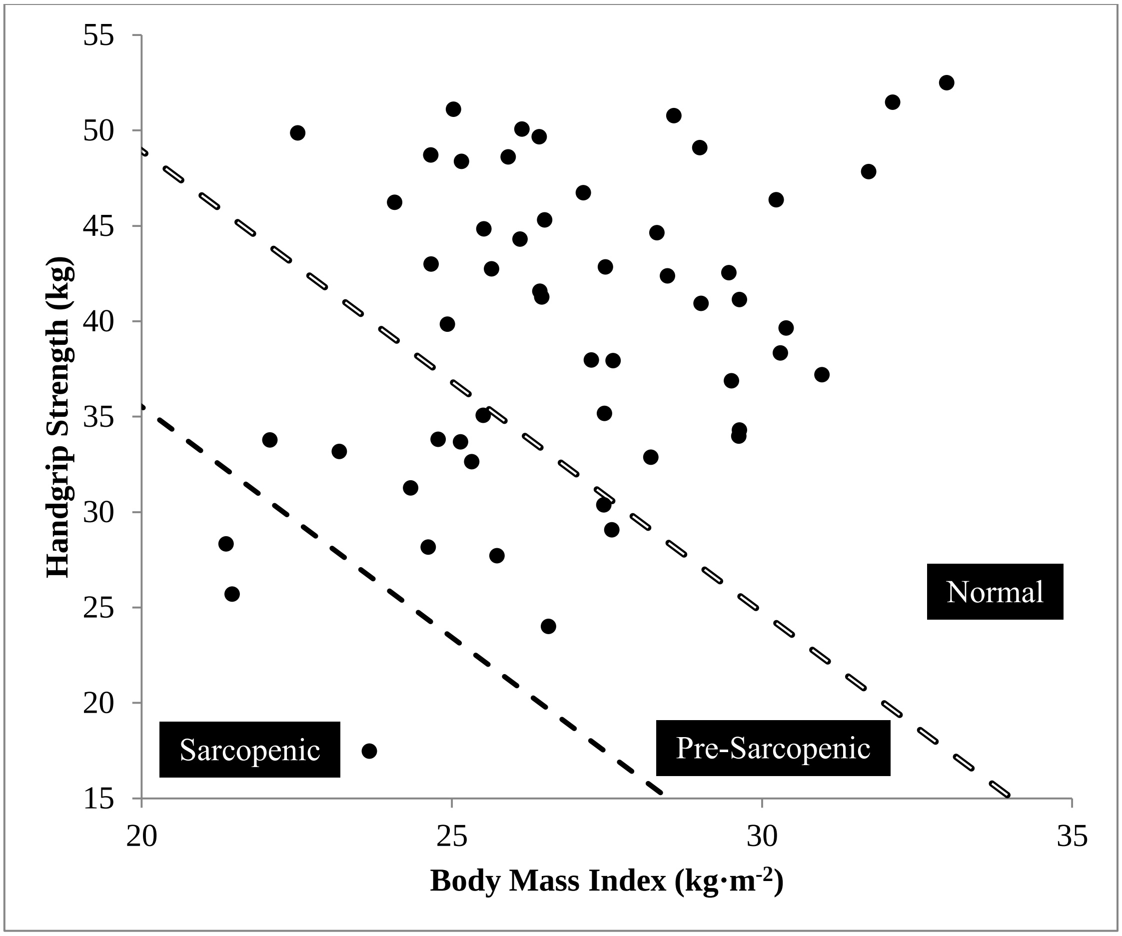


Figure 19. Comparison of individual body mass index and handgrip strength values for men with isoperformance curves representing a relative skeletal muscle index cut-off value of 7.26 kg·m^{-2} (solid line) and 7.84 kg·m^{-2} (7.26 kg·m^{-2} plus standard error of the estimate; compound line).

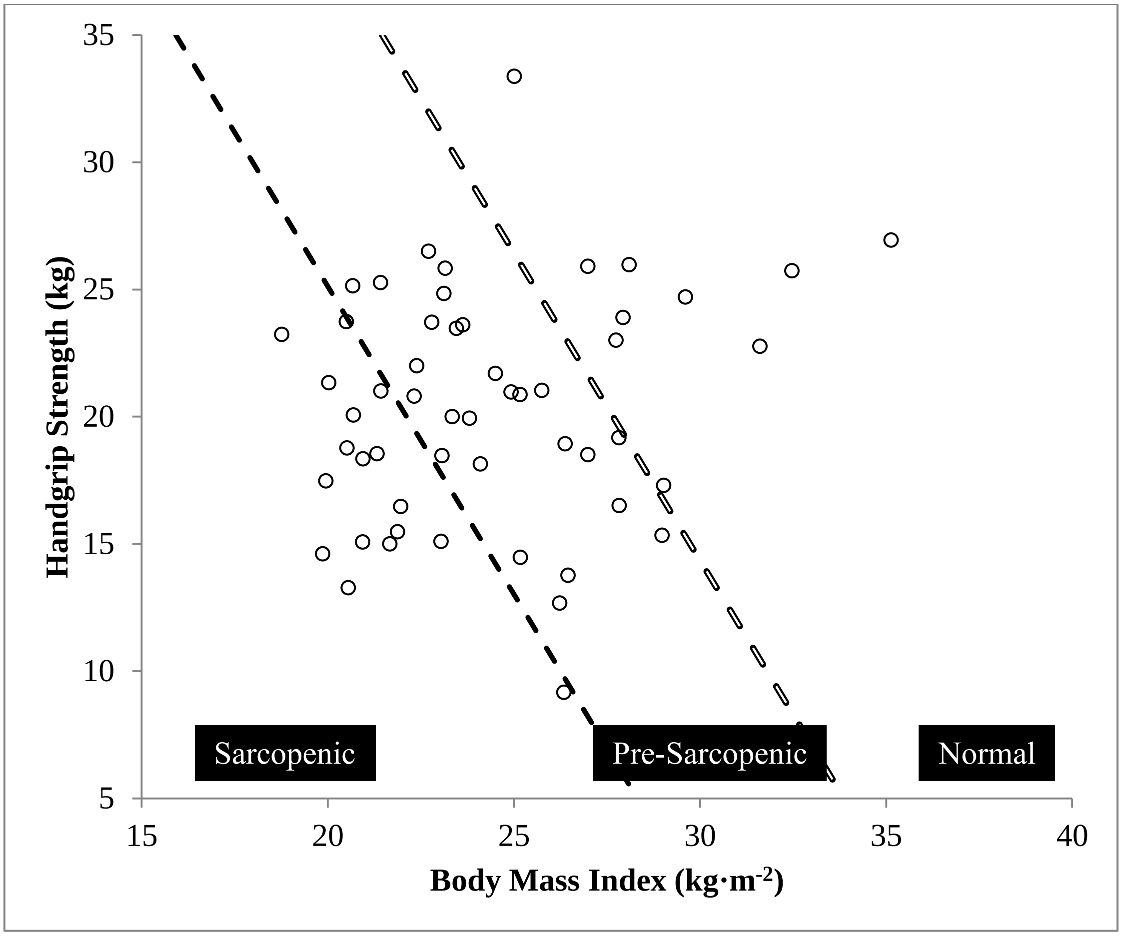


Figure 20. Comparison of individual body mass index and handgrip strength values for women with isoperformance curves representing a relative skeletal muscle index cut-off value of 5.45 kg·m^{-2} (solid line) and 6.03 kg·m^{-2} (7.26 kg·m^{-2} plus standard error of the estimate; compound line).

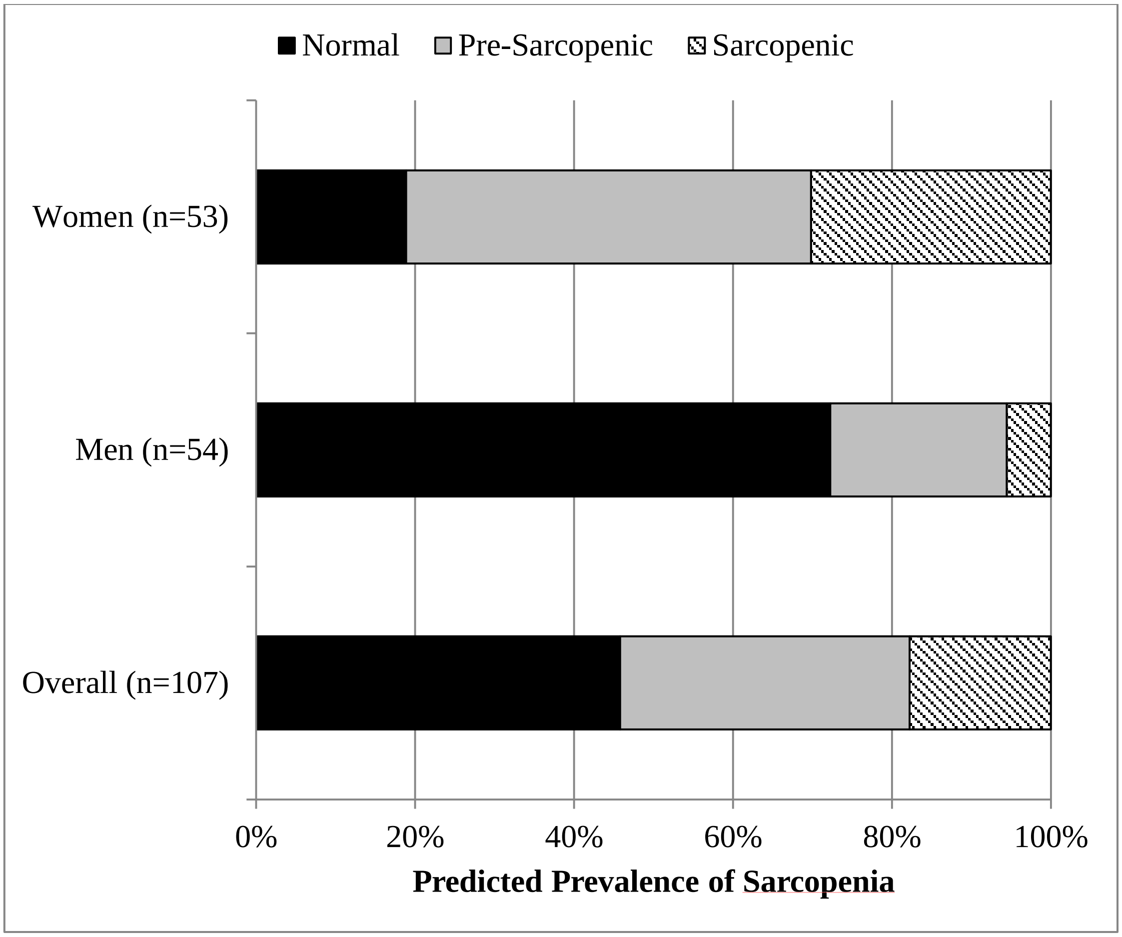


Figure 21. Prevalence values from predicted relative skeletal muscle index for normal muscle mass, pre-sarcopenic, and sarcopenic individuals.

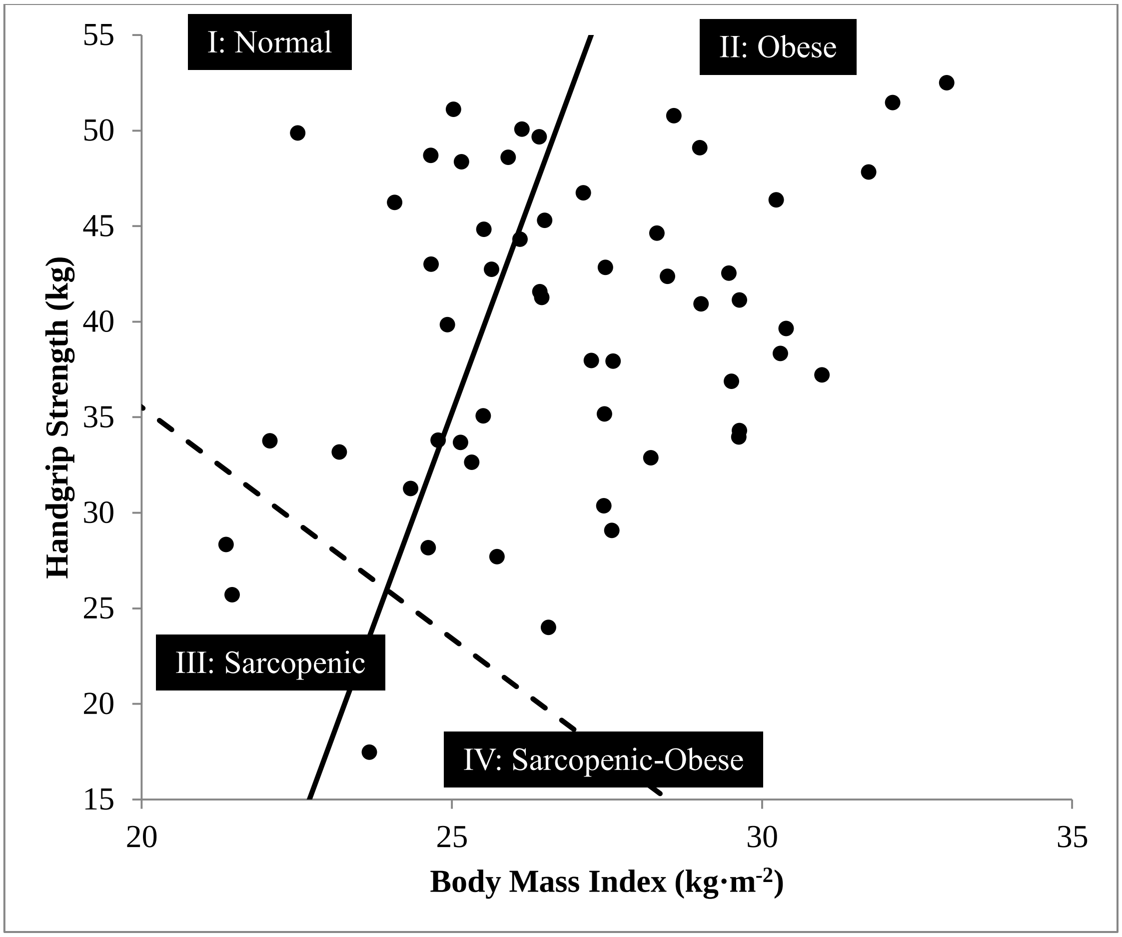


Figure 22. Comparison of individual body mass index and handgrip strength values for men with isoperformance curves representing a relative skeletal muscle index cut-off value of 7.26 kg·m^{-2} (solid line) and a body fat percentage cut-off value of 27% (dashed line).

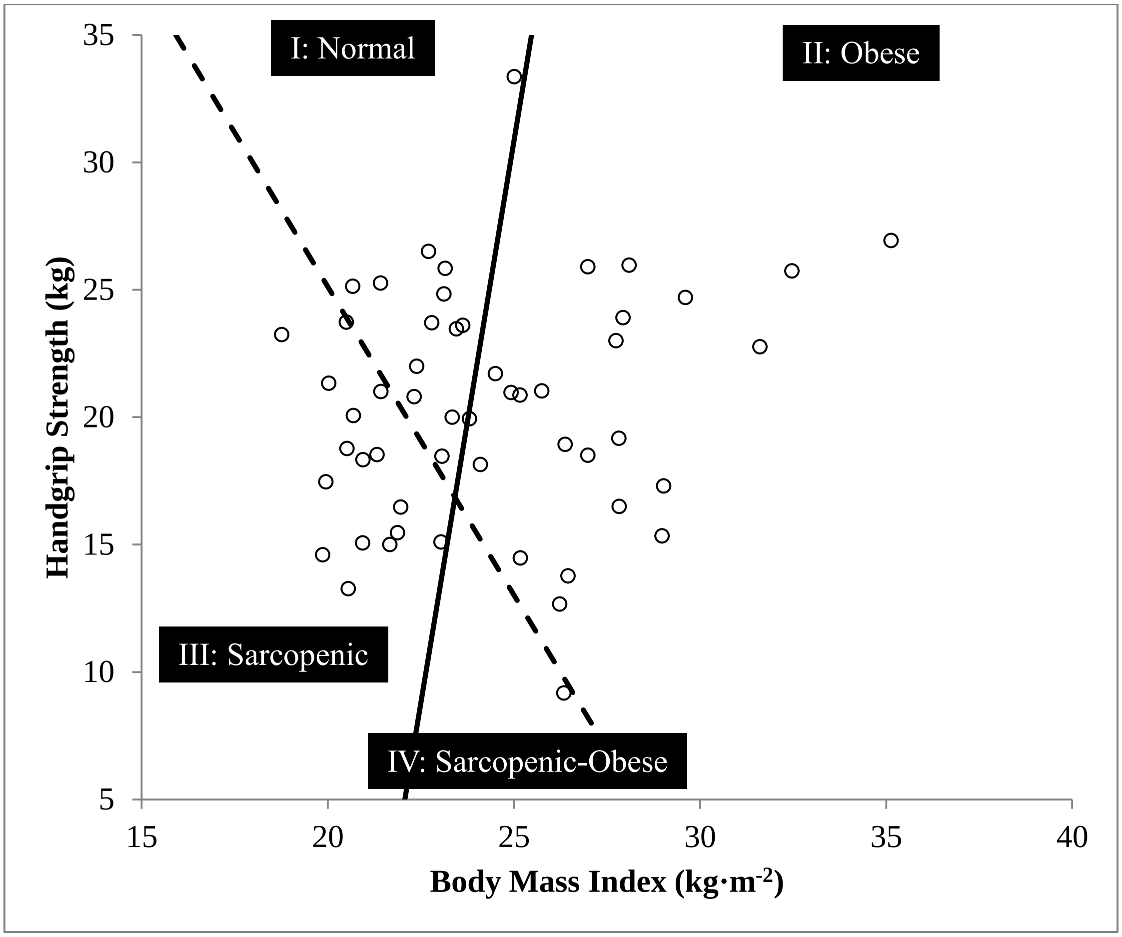


Figure 23. Comparison of individual body mass index and handgrip strength values for women with isoperformance curves representing a relative skeletal muscle index cut-off value of 5.45 kg·m^{-2} (solid line) and a body fat percentage cut-off value of 38% (dashed line).

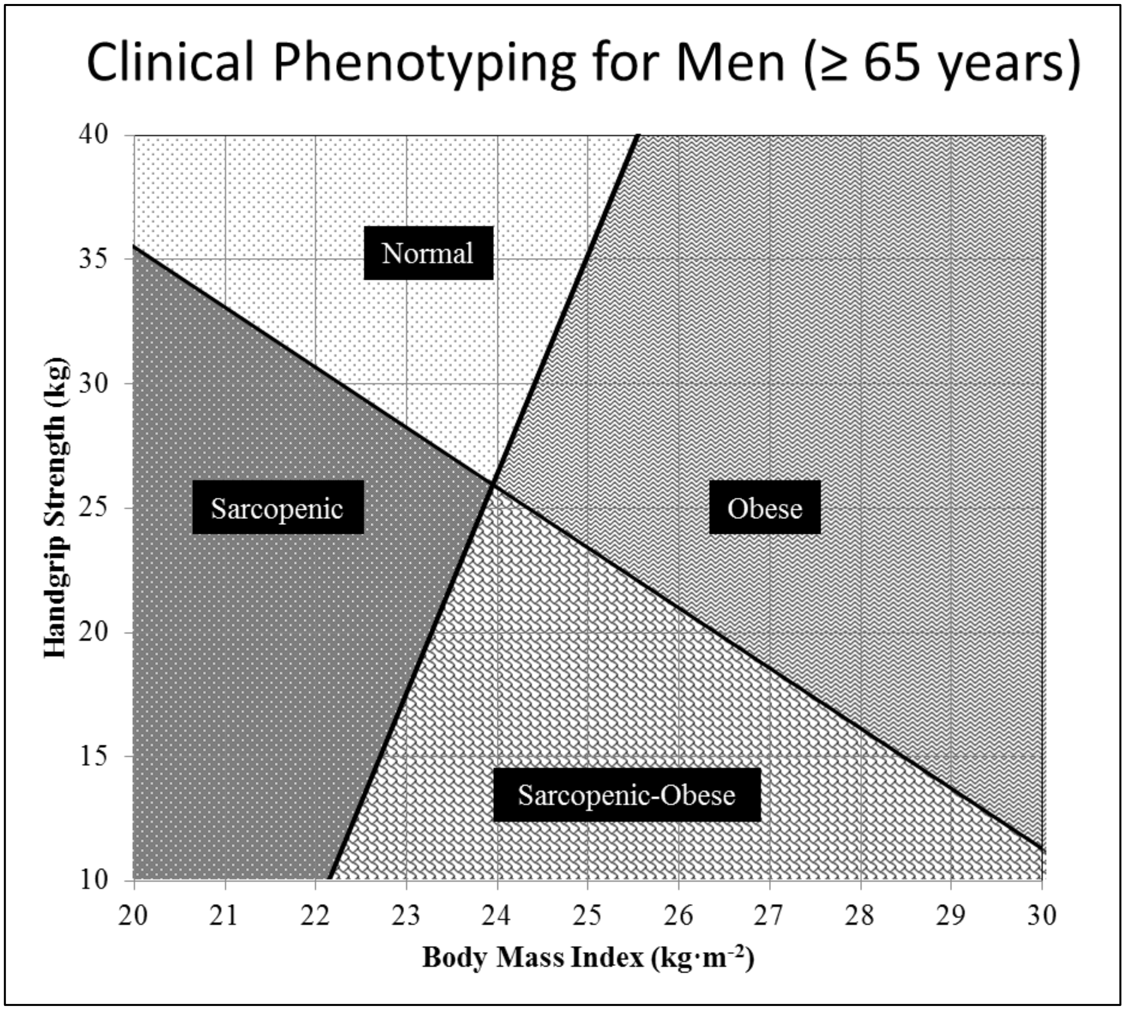


Figure 24. Illustration of the use of isoperformance curves to identify body composition phenotypes in chart form for men.

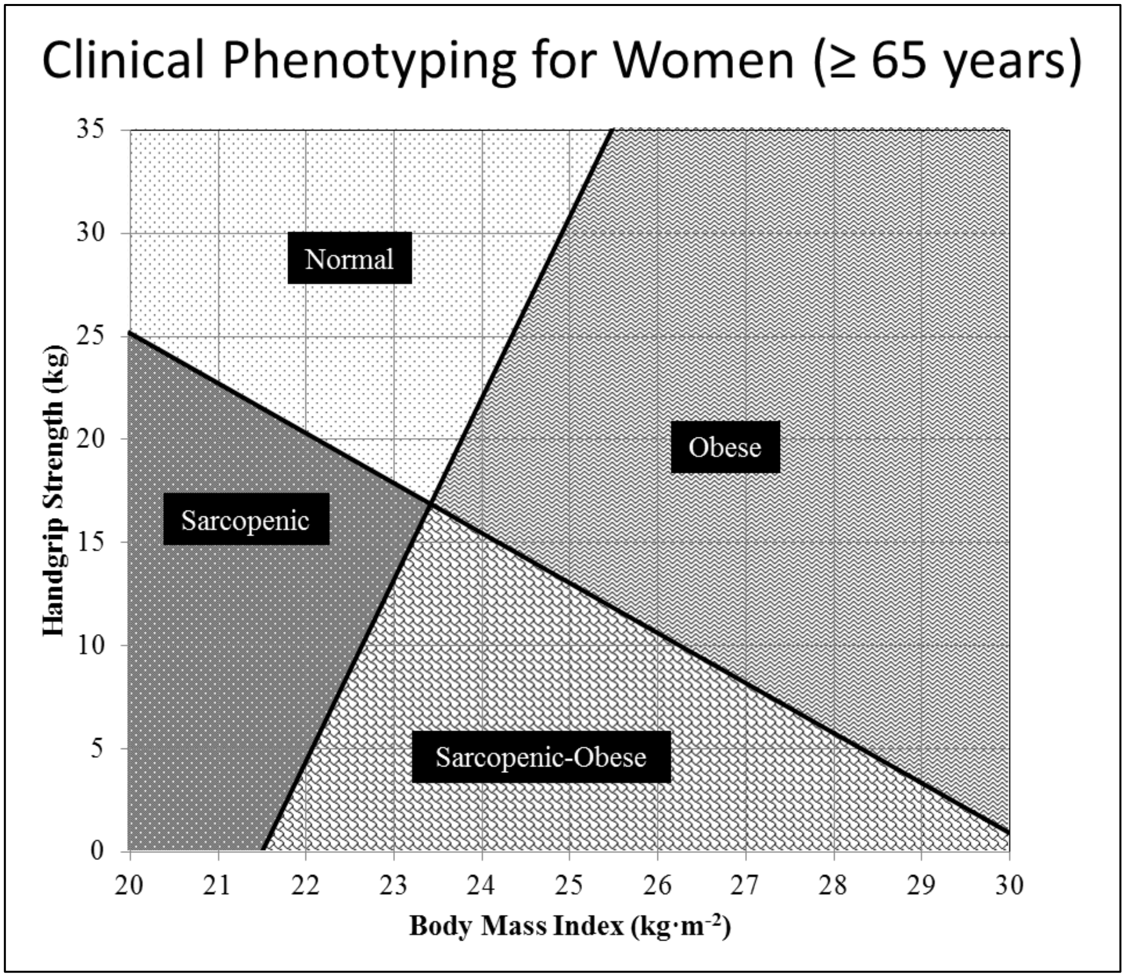
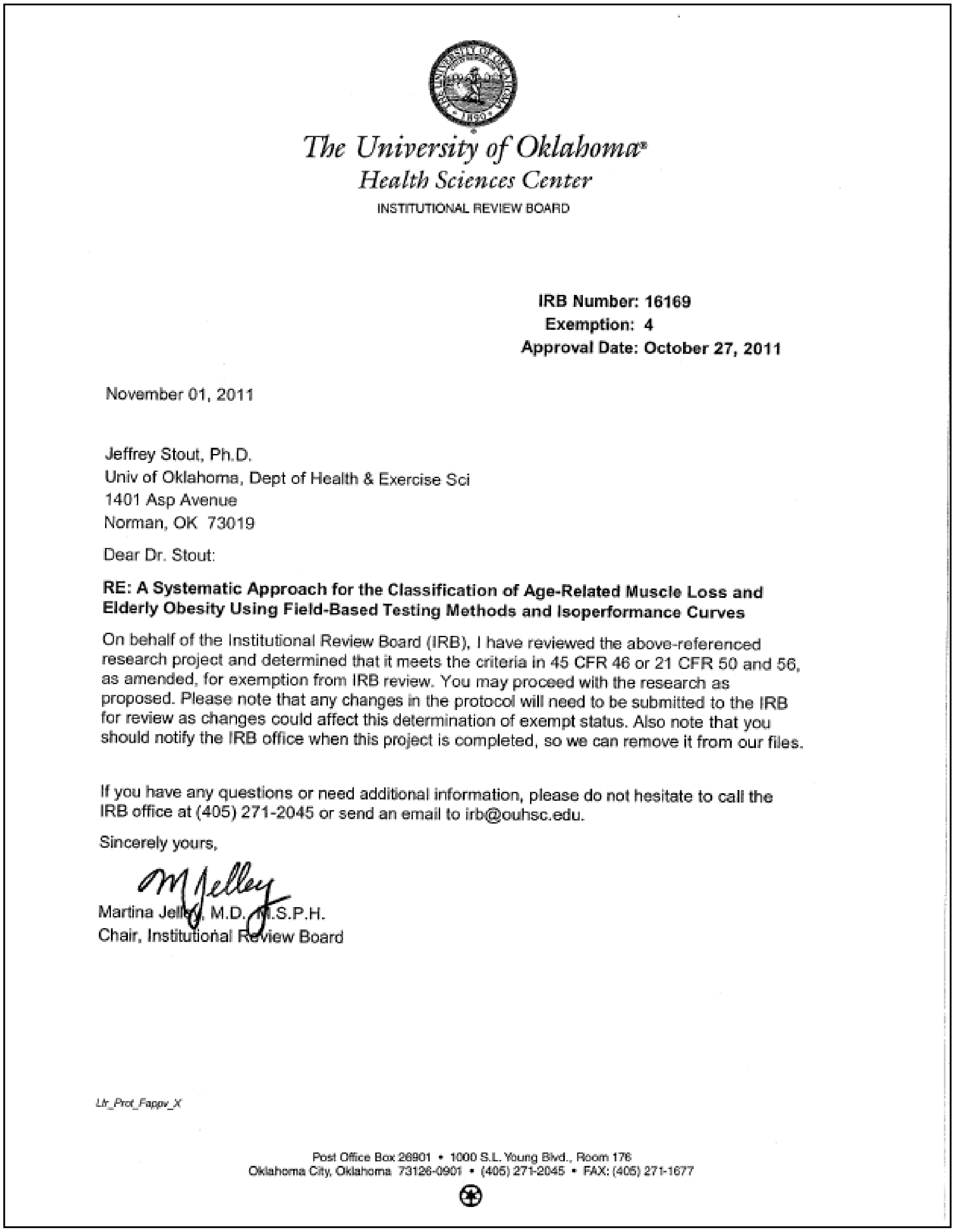


Figure 25. Illustration of the use of isoperformance curves to identify body composition phenotypes in chart form for women.

APPENDIX D

INSTITUTIONAL REVIEW BOARD DOCUMENTATION



The University of Oklahoma®
Health Sciences Center
INSTITUTIONAL REVIEW BOARD

IRB Number: 16169
Exemption: 4
Approval Date: October 27, 2011

November 01, 2011

Jeffrey Stout, Ph.D.
Univ of Oklahoma, Dept of Health & Exercise Sci
1401 Asp Avenue
Norman, OK 73019

Dear Dr. Stout:

RE: A Systematic Approach for the Classification of Age-Related Muscle Loss and Elderly Obesity Using Field-Based Testing Methods and Isoperformance Curves

On behalf of the Institutional Review Board (IRB), I have reviewed the above-referenced research project and determined that it meets the criteria in 45 CFR 46 or 21 CFR 50 and 56, as amended, for exemption from IRB review. You may proceed with the research as proposed. Please note that any changes in the protocol will need to be submitted to the IRB for review as changes could affect this determination of exempt status. Also note that you should notify the IRB office when this project is completed, so we can remove it from our files.

If you have any questions or need additional information, please do not hesitate to call the IRB office at (405) 271-2045 or send an email to irb@ouhsc.edu.

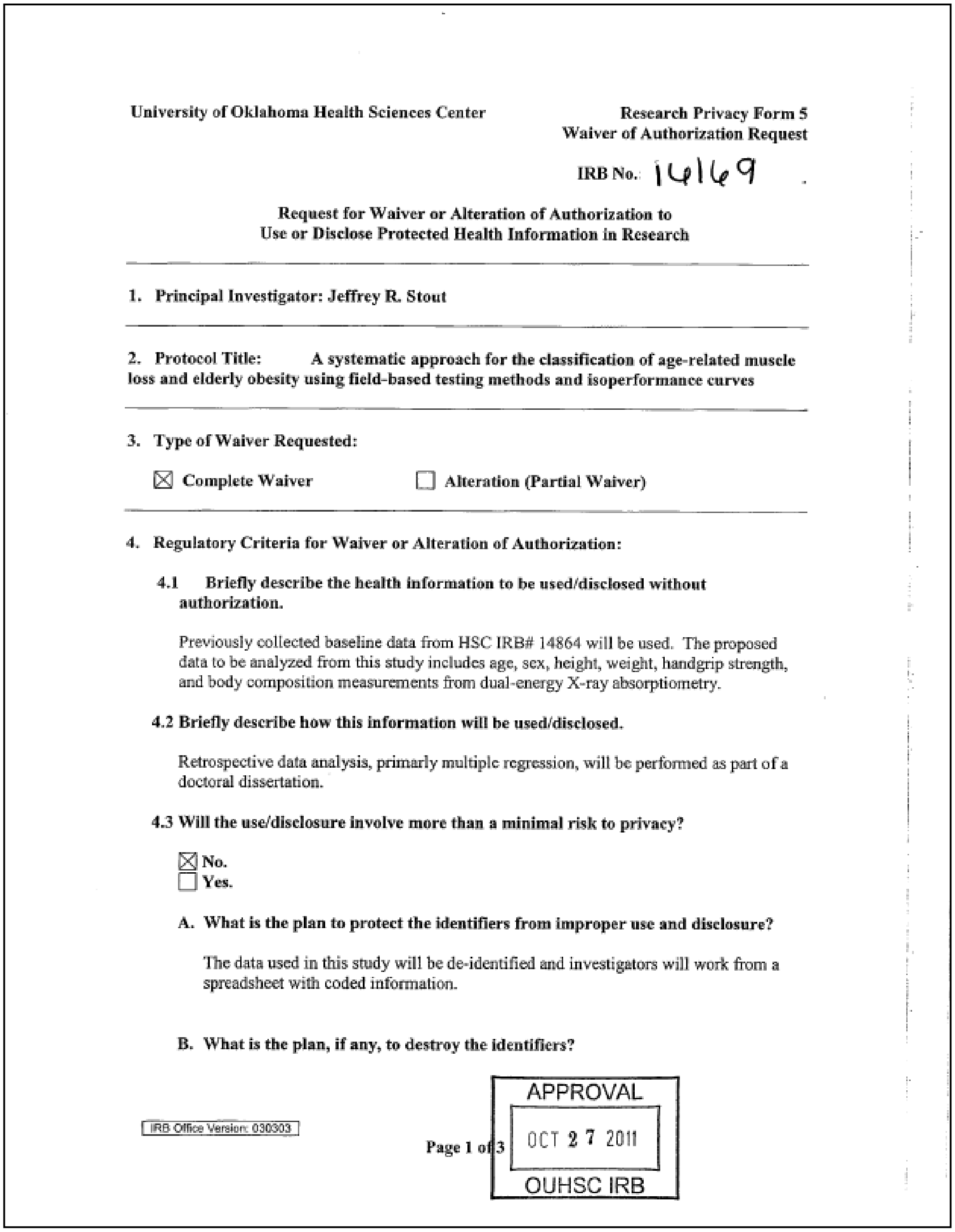
Sincerely yours,

M Jelley

Martina Jelley, M.D., M.S.P.H.
Chair, Institutional Review Board

Ltr_Prot_Fappv_X

Post Office Box 26901 • 1000 S.L. Young Blvd., Room 176
Oklahoma City, Oklahoma 73126-0901 • (405) 271-2045 • FAX: (405) 271-1677



University of Oklahoma Health Sciences Center

Research Privacy Form 5
Waiver of Authorization Request

IRB No.: 14169

Request for Waiver or Alteration of Authorization to
Use or Disclose Protected Health Information in Research

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1. Principal Investigator: Jeffrey R. Stout

---

2. Protocol Title: A systematic approach for the classification of age-related muscle loss and elderly obesity using field-based testing methods and isoperformance curves

---

3. Type of Waiver Requested:

☒ **Complete Waiver** ☐ **Alteration (Partial Waiver)**

---

4. Regulatory Criteria for Waiver or Alteration of Authorization:

4.1 Briefly describe the health information to be used/disclosed without authorization.

Previously collected baseline data from HSC IRB# 14864 will be used. The proposed data to be analyzed from this study includes age, sex, height, weight, handgrip strength, and body composition measurements from dual-energy X-ray absorptiometry.

4.2 Briefly describe how this information will be used/disclosed.

Retrospective data analysis, primarily multiple regression, will be performed as part of a doctoral dissertation.

4.3 Will the use/disclosure involve more than a minimal risk to privacy?

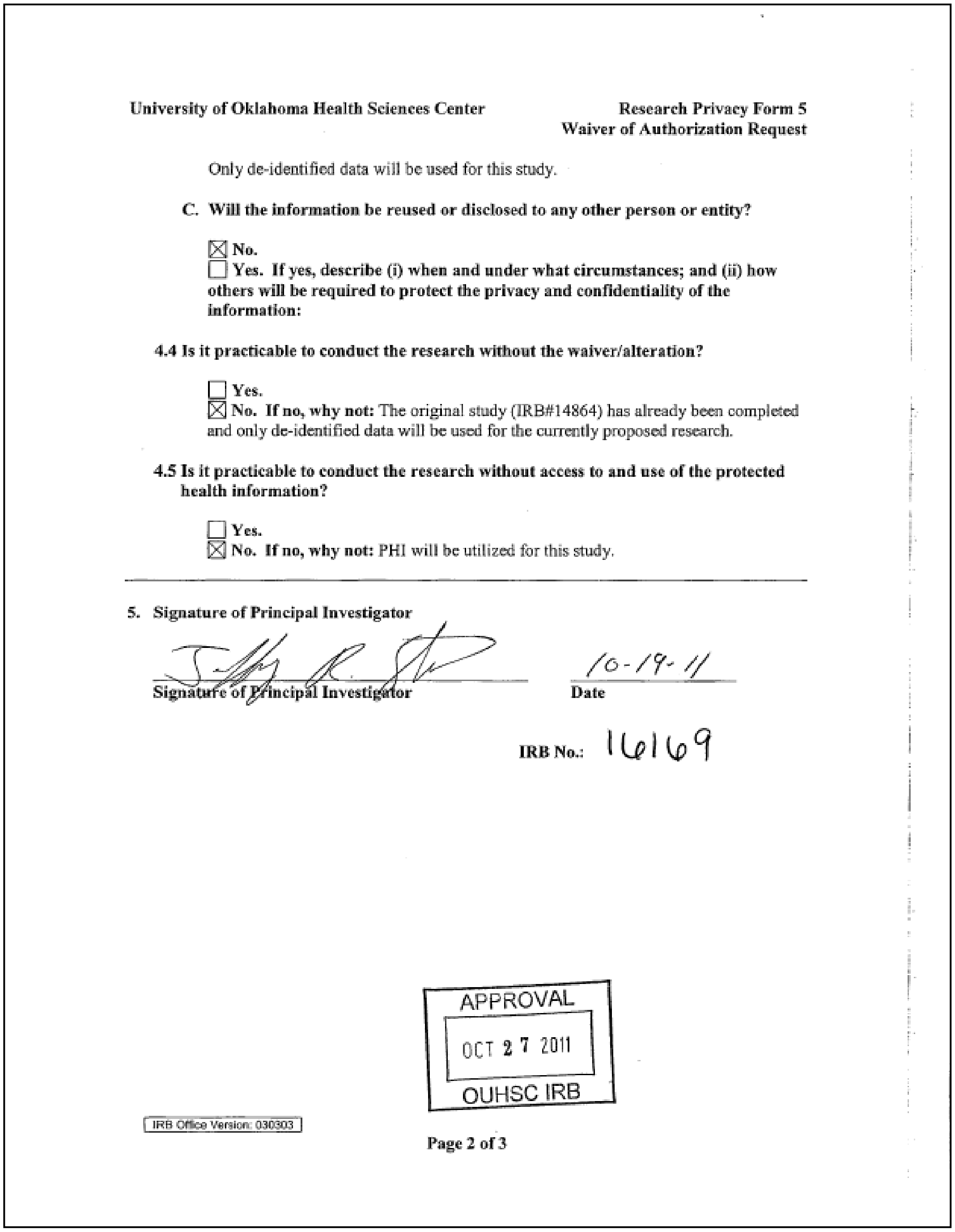
☒ **No.**
☐ **Yes.**

A. What is the plan to protect the identifiers from improper use and disclosure?

The data used in this study will be de-identified and investigators will work from a spreadsheet with coded information.

B. What is the plan, if any, to destroy the identifiers?

APPROVAL
OCT 27 2011
OUHSC IRB



Only de-identified data will be used for this study.

C. Will the information be reused or disclosed to any other person or entity?

☒ **No.**
☐ **Yes. If yes, describe (i) when and under what circumstances; and (ii) how others will be required to protect the privacy and confidentiality of the information:**

4.4 Is it practicable to conduct the research without the waiver/alteration?

☐ **Yes.**
☒ **No. If no, why not:** The original study (IRB#14864) has already been completed and only de-identified data will be used for the currently proposed research.

4.5 Is it practicable to conduct the research without access to and use of the protected health information?

☐ **Yes.**
☒ **No. If no, why not:** PHI will be utilized for this study.

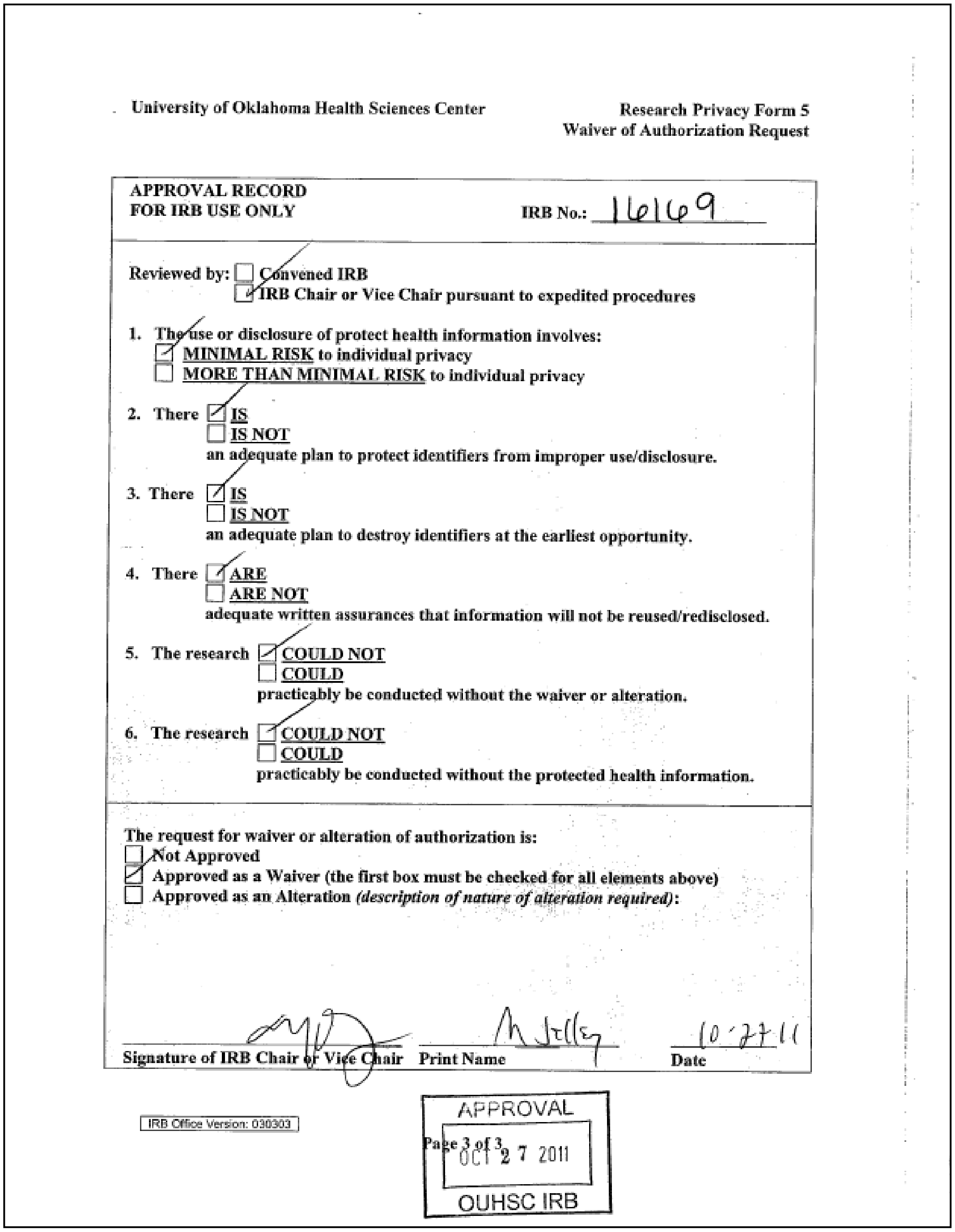
---

5. Signature of Principal Investigator

Signature of Principal Investigator **Date** 10-19-11

IRB No.: 16169

APPROVAL
OCT 27 2011
OUHSC IRB



University of Oklahoma Health Sciences Center

Research Privacy Form 5
Waiver of Authorization Request

APPROVAL RECORD
FOR IRB USE ONLY

IRB No.: 16169

Reviewed by: ☐ Convened IRB
☑ IRB Chair or Vice Chair pursuant to expedited procedures

1. The use or disclosure of protect health information involves:
   ☑ **MINIMAL RISK** to individual privacy
   ☐ **MORE THAN MINIMAL RISK** to individual privacy

2. There ☑ **IS**
   ☐ **IS NOT**
   an adequate plan to protect identifiers from improper use/disclosure.

3. There ☑ **IS**
   ☐ **IS NOT**
   an adequate plan to destroy identifiers at the earliest opportunity.

4. There ☑ **ARE**
   ☐ **ARE NOT**
   adequate written assurances that information will not be reused/redisclosed.

5. The research ☑ **COULD NOT**
   ☐ **COULD**
   practicably be conducted without the waiver or alteration.

6. The research ☑ **COULD NOT**
   ☐ **COULD**
   practicably be conducted without the protected health information.

The request for waiver or alteration of authorization is:
☐ Not Approved
☑ Approved as a Waiver (the first box must be checked for all elements above)
☐ Approved as an Alteration *(description of nature of alteration required)*:

Signature of IRB Chair or Vice Chair

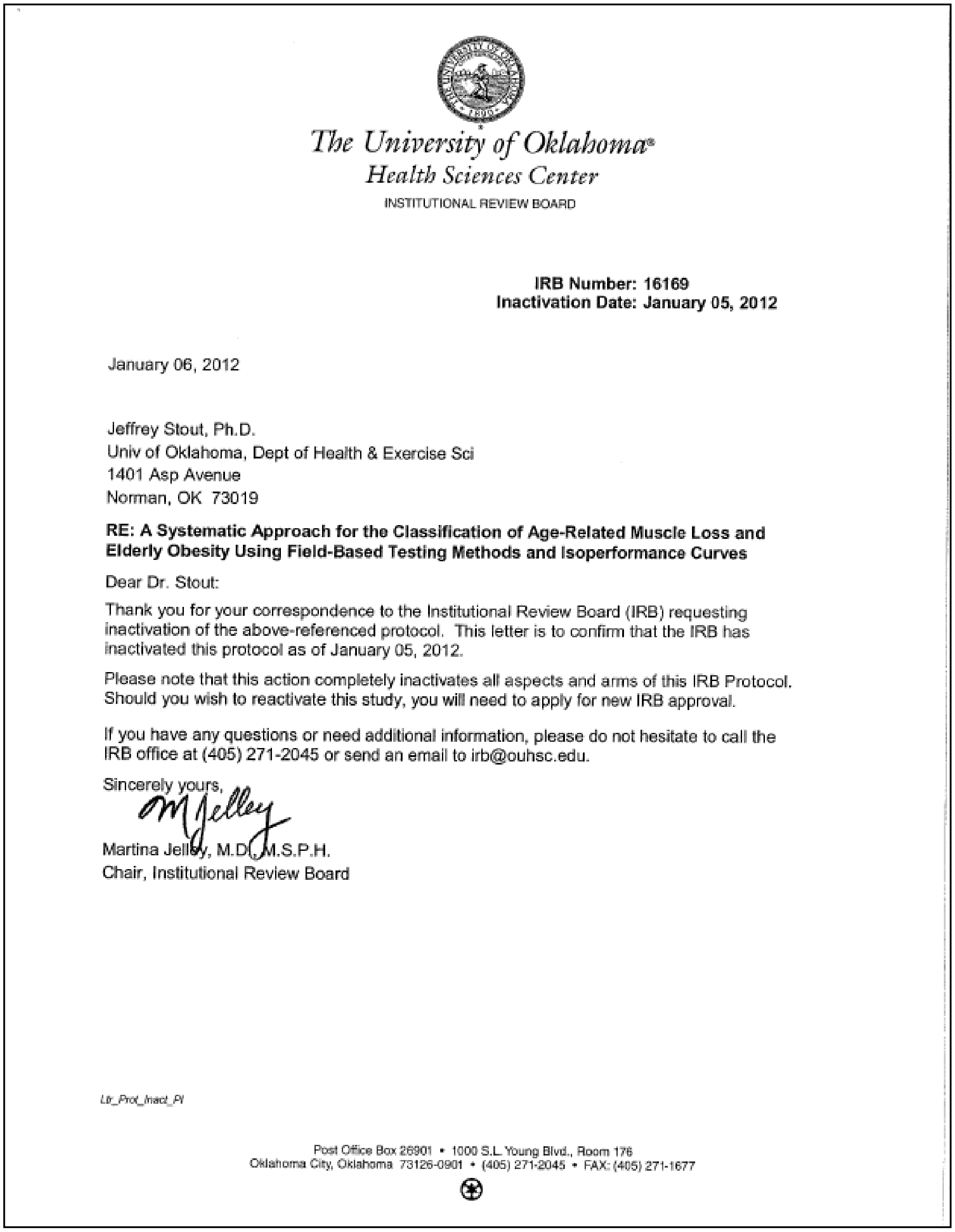
Print Name: M Jelley

Date: 10-27-11

IRB Office Version: 030303

Page 3 of 3

APPROVAL
OCT 2 7 2011
OUHSC IRB



The University of Oklahoma®
Health Sciences Center
INSTITUTIONAL REVIEW BOARD

IRB Number: 16169
Inactivation Date: January 05, 2012

January 06, 2012

Jeffrey Stout, Ph.D.
Univ of Oklahoma, Dept of Health & Exercise Sci
1401 Asp Avenue
Norman, OK 73019

RE: A Systematic Approach for the Classification of Age-Related Muscle Loss and Elderly Obesity Using Field-Based Testing Methods and Isoperformance Curves

Dear Dr. Stout:

Thank you for your correspondence to the Institutional Review Board (IRB) requesting inactivation of the above-referenced protocol. This letter is to confirm that the IRB has inactivated this protocol as of January 05, 2012.

Please note that this action completely inactivates all aspects and arms of this IRB Protocol. Should you wish to reactivate this study, you will need to apply for new IRB approval.

If you have any questions or need additional information, please do not hesitate to call the IRB office at (405) 271-2045 or send an email to irb@ouhsc.edu.

Sincerely yours,

M Jelley

Martina Jelley, M.D., M.S.P.H.
Chair, Institutional Review Board

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