EXPLORING THE RELATIONSHIP BETWEEN BODY MASS INDEX AND SKINFOLD THICKNESS IN CHILDREN AND ADOLESCENTS

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A thesis submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the Master of Arts degree in the Department of Exercise and Sport Science (Exercise Physiology).

Chapel Hill
2010

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ABSTRACT

JEFFREY COOPER: Exploring the Relationship Between Body Mass Index and Skinfold Thickness in Children and Adolescents
(Under the direction of Robert McMurray, PhD)

This study explored the relationship between body mass index and sum of two skinfolds (S2SF) in children and adolescents. Variables examined include age group, race/ethnicity, and sex. A sample of 5249 children and adolescents, 6-17 years old, from the 2005-2006 National Health and Nutrition Examination Surveys were divided into four age-groups as follows: ages 6-8, ages 9-11, ages 12-14, and ages 15-17. A significant effect ($p < 0.0001$) was found when regressing BMI on: S2SF ($R^2 = 0.723$) ; S2SF and race/ethnicity ($R^2 = 0.724$); S2SF and sex ($R^2 = 0.748$); S2SF and age group ($R^2 = 0.795$); S2SF, age group, and race/ethnicity ($R^2 = 0.796$); S2SF, age group, and sex ($R^2 = 0.815$). The relationship between BMI and S2SF was linear for all but two male groups, but varied by age group and race/ethnicity for females. Findings suggest that no single equation best fits all children and adolescents.

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LIST OF ABBREVIATIONS

Body Mass Index = [BMI]

National Health and Nutrition Examination Survey = [NHANES]

Sum of Skinfolds = [SSF]

Sum of Triceps and Subscapular Skinfolds = [S2SF]

CHAPTER 1

BASIS OF STUDY

Introduction

Weight gain and fat storage have come full circle in recent years. In times past, when major health concerns were food shortage and subsequent malnutrition, weight gain and fat storage were often viewed as signs of health and prosperity. However, with the rise in standards of living across the globe, the ability to secure an adequate energy intake has also increased, and with it the number of individuals who are classified as obese (WHO, 2000). Obesity, the excess accumulation of body fat stores, is spreading quickly around the world. In 2000, the World Health Organization (WHO) and the International Obesity Task Force (IOTF) recognized excess body weight as “the most prevalent nutrition-related problem in western societies…[with] childhood obesity rapidly emerging as a global epidemic” (WHO, 2000).

Obesity has become a key risk factor for numerous chronic and non-communicable diseases (WHO, 2000). These include increased rates of: infection, insulin resistance, cardiovascular disease, diabetes mellitus, nonalcoholic fatty liver disease, obstructive sleep apnea, systemic inflammatory response syndrome, and several types of cancer … all of which affect mortality rates (Caroli et al., 2007; Freedman et al., 1999; Krassas & Tzotzas, 2004; Maleka-Tendera et al., 2004; Nooyens et al., 2007). Obesity during childhood increases the risk of mortality, regardless of whether or not the obesity lasts into adulthood

(Pecoraro et al., 2003). It is important to note that excess adipose tissue, rather than excess weight in general, is the cause of the comorbid conditions (Prentice & Jebb, 2001).

In order to study the increasing prevalence of obesity across the globe, there exists a need for classifying individual health status according to varying levels of adiposity (Gallagher et al., 2000). Methods for assessing body fat range from highly accurate but quite costly dual energy x-ray absorptiometry (DEXA) scans, to the more basic but less accurate body mass index (BMI). The ideal measure should meet several of the sample criteria set forth by Power et al. (1997). These include: accurately estimating body fat; containing a small amount of measurement error, and thus having high precision; being easily utilized and cost-efficient, and thus highly accessible; providing a least-invasive measurement that is acceptable to the subject; and exhibiting well-documented reference values. An additional caveat for the ideal measure is to estimate body fat independent of other covariates of body mass, such as height (Caroli et al., 2007). Unfortunately, no existing measure satisfies all of these criteria. Anthropometric measurements, such as BMI and sum of skinfold thickness (SSF), do an ample job of satisfying many of these criteria, and thus are often used for large-scale screening of obesity. Physiological and chemical changes due to growth/development in children and adolescents further complicate body composition testing and make defining weight status more difficult (Rolland-Cachera, 1993). Another major issue is the lack of a standard definition for obesity in children and adolescents (Cole et al., 2000; Dehghan et al., 2005).

Presently, the most accepted anthropometric measure for assessing overweight and obesity is BMI (Caroli et al., 2007). While BMI is the standard for defining obesity in adults, the use of BMI for defining obesity in children and adolescents is not universally accepted. A major assumption when utilizing BMI is that body mass, adjusted for height in meters squared (m^2), is representative of body fat percentage (Gallagher et al., 2000). The main issue is that although BMI correlates moderately with body fat ($r \leq 0.7$), BMI is not a direct measure of body fat (Freedman et al., 2009). The National Institutes of Health (NIH) and the WHO utilize BMI to classify subjects into three categories of bodyweight (Gallagher et al., 2000). For adults, BMI values in excess of 25 and 30 indicate *overweight* and *obese*, respectively, while those less than 18.5 are considered *low healthy* (US DHHS, 1998; WHO, 1998). Unfortunately, these categories are not applicable to children and adolescents. When evaluating children and adolescents, the Centers for Disease Control (CDC) presently utilizes the cut-points of ≥ 95th percentile BMI-for-age as *obese*, and < 95th but ≥ 85th percentile BMI-for-age as *overweight* (Freedman et al., 2006; Dehghan et al., 2005). The CDC utilized data from 1963-1995 when developing the CDC 2000 growth charts, and as such the charts are not representative of the present US population (Krebs et al., 2007). Studies have shown a high specificity but a low sensitivity for BMI during adolescence as a predictor for being overweight as an adult (Nooyens et al., 2007). This means that, using BMI scores from adolescence, researchers can reasonably predict who *will* be overweight as an adult, but are unable to predict who *will not* be overweight. While BMI is acceptable to the subject and highly reproducible (height, $r = 0.9998$; weight, $r = 0.9999$), its correlation with body fat is weaker ($r \leq 0.7$) than other measures, such as skinfold thickness (Foster & Berenson, 1987; Freedman et al., 2009). BMI does not distinguish between lean body mass (i.e., fat free mass) and fat body mass, and thus can be misleading based on individual differences in body composition. Individuals with highly dissimilar body composition can have the same BMI. For example, during one study a 10-y-old boy with a fat mass index of 1.6 kg/m^2 and an 11-

y-old boy with a fat mass index of 6.9 kg/m^2 both had a BMI of ~20 kg/m^2, despite one boy having almost four times the fat mass index than the other (Freedman et al., 2005). An example of a false positive would be an individual with a large amount of lean muscle mass receiving a higher BMI score than his/her actual adipose levels would warrant. An example of a false negative would be an individual with a little too much body fat receiving a lower BMI score than his/her actual adipose levels would warrant. In the case of the false positive, the individual may engage in unnecessary dieting/lifestyle changes, whereas the false negative individual may not realize that he/she needs to engage in dietary/lifestyle changes.

Another measure for assessing body fat is skinfold thickness. This technique estimates body fat based on measurements of subcutaneous fat at various sites throughout the body, most commonly the triceps and subscapular regions (Power et al., 1997). Rolland-Cachera (1993) demonstrated that one can reasonably predict total body fat from skinfold thickness at the triceps, and percent body fat from skinfold thickness at the subscapular site. (Power et al., 1997). Skinfold thickness has been shown to correlate well (r = 0.84-0.93) with body fat, dependent upon the site measured and the sex of the subject (Nooyens et al., 2007). Due to its direct measurement of [subcutaneous] body fat, skinfold thickness is more closely associated with body fat than is BMI (Freedman et al., 2009). The ability to replicate skinfold measurements at the triceps and subscapular regions has been shown to be quite high (r = 0.98) with proper evaluator technique (Freedman et al., 2009). The sum of two skinfold thicknesses (S2SF) utilizes the two most common skinfold measurement sites, the triceps and subscapular skinfolds, while avoiding a compounding of measurement error that would be present if a ratio was used (Power et al., 1997).

There are several potential factors that influence body fat independent of the measurement tool used. Fat mass increases in terms of absolute values with increasing age (Caroli et al., 2007). In examining prior research on body fat percentage changes with age, Gallagher et al. (2000) found that sex and race/ethnicity play a role in the rate at which body fat percentage changes with age. Additionally, Wells (2001) found that age, sex, and race/ethnicity will alter the ratio between subcutaneous and total body fat. Even among same-age subjects, the individual at the more advanced sexual maturation stage will have a lower percent body fat (Daniels et al., 1997). As such, examining the utility of body composition measurements requires consideration of age, sex, and race/ethnicity as independent factors that may influence body fat.

The ability to monitor trends in obesity relative to age, race/ethnicity, and sex is critical for epidemiological studies (Speiser et al., 2005). BMI and S2SF may be the two most accessible and cost-effective measures for conducting large-scale obesity screening. If BMI is not highly correlated with percent body fat, then it is not appropriate to use BMI as the sole determinant of an individual's classification as *overweight*/*obese*. Limited research to date has been conducted that examines the relationship between the body composition measurements of BMI and S2SF in children and adolescents. The lack of a universal definition of *overweight* or *obese* in children/adolescents creates difficulty when reviewing previous research examining BMI. Therefore, the purpose of this research study is to examine the relationship between BMI and S2SF, and to explore how this relationship is affected by age, sex, and race/ethnicity. Organization of this research will include information about the variables, research questions and hypotheses, operational definitions, assumptions/delimitations/limitations, literature review, research methodology, results, and a summary conclusion.

Research Questions

1. What is the relationship between body mass index and the sum of two skinfolds in children and adolescents?
2. What is the effect of age on the relationship between body mass index and the sum of two skinfolds, adjusting for race/ethnicity and sex?
3. What is the effect of race/ethnicity on the relationship between body mass index and the sum of two skinfolds with variables age and sex held constant?
4. What is the effect of sex on the relationship between body mass index and the sum of two skinfolds with variables age and race/ethnicity held constant?

Research Hypotheses

1. The relationship between BMI and S2SF will be positive but curvilinear.
2. The correlation between BMI and S2SF will decrease with increasing age.
3. The correlation between BMI and S2SF will be greatest for Non-Hispanic Blacks, lower for Mexican Americans, and be weakest for Non-Hispanic Whites.
4. The correlation between BMI and S2SF will be stronger for females than males.

Operational Definitions

1. Body Mass Index – Index for relating an individual's body weight to height. The body mass index (BMI) is a person's weight in kilograms (kg) divided by their height in meters (m) squared.

2. Sum of Two Skinfolds – S2SF thickness is a direct measure of subcutaneous fat, in millimeters (mm), at the triceps and subscapular regions.
3. Obesity – Excess accumulation of body fat. There is currently no universal definition for defining obesity in children.

Assumptions

1. All instrumentation and software used was reliable (skinfold caliper, scales, and stadiometer).
2. Application of anthropometric data measurements was consistent across all subjects.
3. Skinfold thickness is a surrogate for body fat.
4. Body mass index is a surrogate for body fat.

Delimitations

1. Subjects were participants in the 2005-2006 National Health and Nutrition Examination Survey.

Limitations

1. Analyses was conducted on subjects in the race/ethnicity categories of Non-Hispanic White, Non-Hispanic Black, and Mexican American. Sample sizes for other race/ethnicity categories (Other – Hispanic and Other – Race, including multi-racial) were too small for meaningful analysis.
2. The use of multiple recorders for skinfold thickness measurements may have resulted in differing values across different subjects.
3. Subjects had varying lifestyles and dietary habits which will effect body composition.

Significance of Study

Epidemiological assessment necessitates the ability to monitor trends in the spread of obesity (Speiser et al., 2005). BMI and S2SF are the two most accessible and cost-effective measures for conducting large-scale obesity screening (Caroli et al., 2007; WHO, 1995). If BMI is not highly correlated with percent body fat, then it is not appropriate to use BMI as the sole determinant of an individual's classification as *overweight*/*obese*. Limited research to date has been conducted that examines the relationship between the body composition measurements of BMI and S2SF in children and adolescents. This study utilized the most recent NHANES data available in order to examine the relationship between BMI and S2SF and the explanatory variables age group, race/ethnicity, and sex. The lack of a universal definition of *overweight* or *obese* in children/adolescents creates difficulty when reviewing previous research examining BMI. Therefore, the purpose of this research study was to examine the relationship between BMI and S2SF, and to explore how this relationship is affected by age, sex, and race/ethnicity. The majority of research on BMI and S2SF deals with adults. Research has continuously shown that differences in body composition exist between children/adolescents and adults (Lohman, 1992). Recent findings regarding increased risk for cardiovascular disease (CVD) risk factors and numerous other diseases associated with childhood obesity, reinforce the urgency in this area. It is important to have a system in place that can provide early identification of children/adolescents who are *overweight*/*obese* in order to allow for early treatment or intervention. As such, understanding the relationship between the two most widely utilized anthropometric measurements is critical.

CHAPTER 2

LITERATURE REVIEW

Introduction

The primary purpose of this literature review is to examine the relationship between body mass index (BMI) and sum of two skinfolds (S2SF) in children and adolescents, and to explore how this relationship is affected by age, sex, and race/ethnicity. This review will provide background information on the history of body composition, the benefits and drawbacks to utilizing BMI or skinfold thickness for body composition measurement, and rationale for a comparison between BMI and S2SF.

Body Composition

Body composition is a term that refers to the makeup of an individual’s body mass, which is comprised of muscle, bone, cartilage/tendon, and fat. Body composition directly relates to the classification of individuals as *overweight* or *obese*. Since obesity negatively impacts an individual’s health status and increases their risk for several diseases, body composition testing at an early age is a critical component of health evaluations. Ebbeling and colleagues (2002) identified the clustering of obesity-related cardiovascular disease (CVD) risk factors in children as young as age 5.

There are several methods available for measuring body composition, including bioelectrical impedance analysis (BIA), dual energy x-ray absorptiometry (DEXA), hydrodensitometry (hydrostatic underwater weighing), and sum of skinfold thickness (SSF). Some of these methods are direct measures of body fat (such as DEXA scans and hydrostatic weighing), while others are indirect measures (such as BIA and SSF) or surrogate measures (such as BMI). DEXA scans are very accurate/precise, but quite costly, and DEXA testing requires the subject to remain motionless (which can be problematic when testing children and adolescents). Hydrostatic weighing is quite accurate/precise, and reasonably inexpensive, but is often not acceptable to the subject, particularly children and adolescents (because the protocol requires the subject to be fully immersed in a water tank). The protocols and equipment required to perform DEXA scans and hydrodensitometry relegate these measures to a research setting at this time. Due to the complications and/or excessive cost of the direct measures, indirect and surrogate measures, such as S2SF and BMI respectively, are most widely utilized for large-scale obesity screening for children and adolescents.

Body Mass Index

History

Body mass index refers to the relationship between an individual's height and weight, and is calculated via the equation: body mass (kilograms) / height (meters) ^{2}. In 1832, during his effort to define the characteristics of the *normal* man, Belgian polymath Adolphe Quetelet developed an equation to describe the standard proportions of the human build (Daniels et al., 1997). Quetelet derived his formula based on analysis of physical characteristics of several hundred men, with no intention of measuring adiposity or obesity (Quetelet, 1842; Eknoyan, 2008). While comparisons of height and weight were used off and on over the years, particularly by the insurance companies, it was not until 1972 that Quetelet's index became widely utilized. Ancel Keys, a professor of physiology studying obesity, performed a large-scale study examining the efficacy of several height-weight formulas in relation to body fat percentage (Keys et al., 1971). Keys found Quetelet's formula to be the best predictor of body fat percentage, and renamed it body mass index (Keys et al., 1971).

BMI provides a simple and cost-effective measurement tool for assessing appropriate weight status. Height and weight measurements are minimally invasive and generally acceptable to the subject. As such, BMI is the most widely utilized diagnostic tool for assessing weight status (Freedman et al., 2008). In 2000, the CDC released updated sex-specific BMI-for-age growth charts in order to allow for BMI interpretation in children and adolescents. The CDC 2000 growth charts provide physicians with a method to track BMI changes in children and adolescents over time (Speiser et al., 2005). The CDC 2000 growth charts utilize the following cut-points: <5th percentile BMI-for-age as *underweight*; ≥ 5th but< 85th percentile BMI-for-age as *healthy weight*; ≥ 85th but< 95th percentile BMI-for-age as *overweight*; and ≥ 95th percentile BMI-for-age as *obese* (Freedman et al., 2006; Dehghan et al., 2005). The CDC utilized data from 1963-1995 when developing the CDC 2000 growth charts, and as such, the charts are not statistically representative of the present US population (Krebs et al., 2007). In addition, the CDC 2000 charts is the derivation from subjective statistical measures rather than from known biological data that relates to an increased risk of morbidity (Speiser et al., 2005).

BMI levels in children and adolescents, as well as adults, correlate with percent body fat to varying degrees according to subject age, race/ethnicity and sex (Daniels et al., 1997; Dietz et al., 1999; Mei et al., 2002; Pietrobelli et al., 1998). BMI tends to increase in a monotonic fashion with age, with differences between sexes seemingly race/ethnicity dependent (Dai et al., 2002; Freedman et al., 2005). In a study on children and adolescents, Daniels et al. (1997) found that for an equivalent BMI: females have greater percent body fat than males; and subjects categorized as *White* have greater percent body fat than *Blacks*. This is in contrast to BMI in adult females, where subjects categorized as *White* have lower BMI than *Blacks* (Clarke et al., 2009). In a study involving 192 children and adolescents between the ages of 7-17, categorized as either *Black* or *White*, Daniels et al. (1997) found BMI correlated with percent body fat [determined by DEXA] as follows: 0.83 for females (regardless of race), but only 0.54 for black males and 0.50 for white males. Clarke et al. (2009) found significant differences in BMI for adults across sex and race/ethnicity when examining subjects categorized as *Black*, *White*, or *Hispanic*. Interestingly, some research studies have found that race/ethnicity appears to play a more significant role in BMI differences among females than in males (Ellis et al., 1999; Fernandez et al., 2003). Correlations of BMI with hydrodensitometry range from 0.82 for females to 0.70 for males, with a correlation of 0.65 between lean body mass and BMI (Garn et al., 1986). BMI correlates to hydrodensitometry much better in females (R = 0.82) than in males (R = 0.70) (Garn et al., 1986). Table 1 provides an overview of the correlations of BMI with percent body fat, broken down by age, race/ethnicity, and sex when possible.

Table 1. Correlations (r) of percent body fat with BMI by ages, race/ethnicity and sex.

	Study	*Race/Ethnicity*	*Males*	*Females*
DEXA	Eisenmann et al. (2002) Ages 3-8	N/A	0.61-0.75	
	Gallagher et al. (2000) Ages 20-80	A, B, W	0.74-0.92	
	Ellis et al. (1999) Ages 3-18	B, H, W	0.34	0.70
	Daniels et al. (1997) Ages 7-17	B	0.54	0.83
		W	0.50	0.83
	Gallagher et al. (1996) Ages 20-94	B	0.63	0.75
		W	0.58	0.72
	Goran et al. (1996) Ages 4-10	B	0.82	0.82
		W	0.71	0.82
	Gutin et al. (1996) Ages 9-11	N/A	0.71	0.87
Hydrodensitometry	Deurenberg et al. (1991) Ages 7-10	N/A	0.59	0.63
	Deurenberg et al. (1991) Ages 11-15	N/A	0.44	0.65
	Deurenberg et al. (1991) Ages 16-20	N/A	0.39	0.55
	Revicki & Israel (1986) Ages 20-70	N/A	0.71	N/A
	Roche et al. (1981) Ages 6-12	N/A	0.68	0.55
	Roche et al. (1981) Ages 13-18	N/A	0.68	0.77
	Wilmore & Behnke (1970) Ages 18-48	N/A	N/A	0.71-0.98

Race/ethnicity: AA - African American, A - Asian, B - Black, H - Hispanic, W - White.

Advantages

BMI is a widely utilized diagnostic tool for assessing weight status (Freedman et al., 2008). BMI has very high reproducibility (height, r = 0.9998; weight, r = 0.9999), however, the accuracy varies according to the degree of fatness when examining children and adolescents; the greater the percent body fat of the individual, the more closely BMI reflects it (Foster & Berenson, 1987; Freedman et al., 2005 & 2009). For example, Freedman et al.

(2005) found the relation of BMI-for-age to fat mass index [fat(kg)/height(m^2)] for males ages 5-8 varies from 0.22 (<50th percentile) to 0.49 (>50th<84th percentile) to 0.96 (≥85th percentile). While BMI is not the most accurate predictor of body fatness, its relationship to cardiovascular disease risk factors ($r = 0.50 – 0.62$) is similar to that of skinfold thickness ($r = 0.47 – 0.62$) (Freedman et al., 2009; Steinberger et al., 2005). Several studies have examined the use of childhood/adolescent BMI to predict overweight as an adult. Guo & Chumlea (1999) were able to predict overweight at 35 years of age (referencing BMI > 28 for males and > 26 for females) with mixed accuracy: excellent prediction at 18 years of age, good prediction at 13 years of age, and only moderate prediction at <13 years of age. In the Guo & Chumlea (1999) study, BMI values > the 60th percentile at 18 years of age correctly predicted overweight at 35 years of age in 81 percent of males and 86 percent of females.

Disadvantages

BMI does not distinguish between lean body mass and fat mass, and thus is a poor surrogate of body fat percentage. The basic BMI formula does not account for variables (such as age, race/ethnicity, sex, maturation stage, and waist:hip ratio) which affect how BMI relates to health (Daniels et al., 1997). The CDC 2000 growth charts include percentile distributions relative to sex and age, but not race/ethnicity. Ethnic background can have a marked impact on BMI [in adults], resulting in either an overestimation (i.e., Black, Polynesian) or an underestimation (i.e., Chinese, Thai, Ethiopian, Indonesian) of body fat (Prentice & Jebb, 2001). The disparity between true body fatness and an individual's BMI can potentially result in a misclassification in regards to health status. The sensitivity of the BMI index is a major drawback, where only about 55% of female and 44% of male adults are correctly diagnosed as obese when compared with diagnosis by hydrodensitometry (Smalley et al., 1990).

Ellis et al. (1999) measured the ability of BMI-for-age to correctly rank children and adolescents (ages 3-18) based on percent body fat by DEXA and found interesting results. For subjects with a ≥95th percent body fat ranking, 90% of females and 70% of males were correctly identified as being *obese*, while 10% of females and 29% of males were incorrectly identified as *overweight* when they were actually *obese* (Ellis et al., 1999). For subjects with a >85th but < 95th percent body fat ranking, 49% of females and 35% of males were correctly identified as being *overweight*; 9% of females and 15% of males were incorrectly identified as *normal* even though they were *obese*; and 42% of females and 50% of males were incorrectly identified as *obese* even though they were *overweight* (Ellis et al., 1999). In a similar study, Freedman and colleagues (2008) examined the ability of BMI-for-age to correctly identify children and adolescents (ages 5-18) based on percent body fat by DEXA, with the addition of race/ethnicity subgroups. Freedman et al. (2008) found that BMI-for-age correctly identified 65% of males and 72% of females categorized as *White*, 83% of males and 89% of females categorized as *Black*, and 82% of males and 88% of females categorized as *Hispanic*. Age-related changes in sexual maturation (and the resulting effects on body composition) further complicate the use of BMI to classify children and adolescents (Prentice & Jebb, 2001). The monotonic increase in BMI with age is problematic in male adolescents, who typically exhibit a decrease in percent body fat from ages 15-18 (Ellis et al., 1999).

The complexity of BMI interpretation increases with children and adolescents due to the requirement of converting BMI to a percentile ranking based on age and sex (Barlow et al., 2007). For example, while calculation of the BMI for two children/adolescents differing in age and sex might yield the same BMI value, that number would place each individual on a different BMI-for-age percentile, thus the scores cannot be compared. Adding to the confusion until recently were the different classifications used for adults (*overweight*, *obese*) and children/adolescents (*at risk for overweight*, *overweight*). The child/adolescent classification *at risk for overweight* was confusing because it corresponds to the adult classification *overweight*, but could be misinterpreted as an individual who is healthy, but might become overweight later, rather than an individual who is borderline overweight (Nooyens et al., 2007). Recently, the CDC updated the language to incorporate matching terminology of *overweight* and *obese* for both children/adolescents (≥ 85th but< 95th percentile BMI-for-age as *overweight*; and ≥ 95th percentile BMI-for-age as *obese*) and adults (BMI ≥25.0 but ≤29.9 as *overweight*, and BMI ≥30.0 as *obese*). Expert committees on BMI continue to push for a common childhood obesity definition as well as standard cutoff points for overweight and obese children and adolescents (Cole et al., 2000; Dehghan et al., 2005).

Skinfolds

History

Skinfold measurement for body composition refers to the use of special calipers to estimate body fat through the measurement of double, compressed thicknesses of subcutaneous fat and skin at various sites of the body (Krebs et al., 2007; Steinberger et al., 2005). As early as 1921, Professor Jindrich Matiegka (1921) reported using a technique that involved measuring the fold of skin and fat with calipers in an effort to evaluate body composition. Presently, measurement of skinfold thickness requires pinching a fold of skin and subcutaneous fat using the thumb and index finger, pulling it away from the muscle tissue, and then using a pincer-type caliper to measure the thickness (McArdle et al., 2009).

The calipers exert a constant tension (10 g*mm^{-2}) and require reading within 2 seconds of application in order to avoid skinfold compression (McArdle et al., 2009). Several anatomical sites exist for skinfold measurements, including: abdominal, biceps, calf, chest, iliac crest, midaxillary, subscapular, suprailiac, upper thigh, and triceps. Select skinfold sites relate very well to overall body fatness, dependent upon the sex and age of the subject (Lohman, 1992). Technicians generally take 2-4 measurements, in rotational order, at each selected site on the right side of the body (McArdle et al., 2009). There are two primary ways to utilize the skinfold thickness measurements to provide knowledge about body fat and its distribution. The first involves summing the skinfold measurements to indicate relative fatness, while the second requires the application of skinfold measurements to population-specific equations to estimate body density or body fat percent (McArdle et al., 2009). In addition, Brook and colleagues (1971) demonstrated that skinfold measurements correlate very well with total body water (r = 0.985), which can then be used to calculate total body fat.

In order to estimate body fat, skinfold measurement conversion equations follow the research-backed assumption that ~50% of fat is located subcutaneously and ~50% is visceral and organ fat; thus measuring subcutaneous fat provides a value equal to ~50% of total body fat (McArdle et al., 2009; Rodriguez et al., 2005). In a study examining the additive effect of moving from the sum of two skinfolds to the sum of six skinfolds, Dai and colleagues (2002) found no further differentiation between groups, thus there appears to be no need to add the extra skinfold sites. In particular, the triceps and subscapular skinfolds correlate highest with percent body fat, and thus are the two best sites for estimation of body fat in children and adolescents (Freedman et al., 2009; Freedman et al., 2007; Mei et al., 2007; Nooyens et al., 2007; Dai et al., 2002; Deurenberg et al., 1990; Cronk et al., 1982). The anatomic location for these two sites are as follows: tricep – vertical fold taken at the midpoint between the acrosion process and the olecranon process on the posterior midline of the right upper arm; subscapular – oblique fold taken on the diagonal line from the vertebral border to 1-2 cm below the inferior angle of the scapula (McArdle et al., 2009).

Various body fat estimation equations using S2SF have been cross-validated numerous times for accuracy (Lohman, 1992). Boye et al. (2002) observed significantly higher skinfold measurements for females than for males when examining children and adolescents ranging from ages 6-18, which is consistent with the findings of Dai et al (2002). SSF tends to reflect a growth pattern similar to that of percent body fat (Dai et al., 2002). In addition, Campanozzi and colleagues (2008) found a very high correlation ($R^2 = 0.9284$) between lean body mass calculated by DEXA versus SSF. S2SF allows for accurate estimations of percent body fat based on hydrodensitometry determinations, with standard error ranges of only 0.2-2.3%, an amount that is “barely biologically meaningful” (Deurenberg et al., 1990). When utilizing appropriate skinfold thickness equations, predicted percent body fat is within 3-5% body fat units compared to calculations from hydrodensitometry (McArdle et al., 2009). Table 2 provides an overview of the correlations of S2SF with percent body fat, broken down by age, race/ethnicity, and sex when possible.

Table 2. Correlations (r) of percent body fat with S2SF by ages, race/ethnicity and sex.

	Study	*Race/Ethnicity*	*Males*	*Females*
DEXA	Kutac & Gajda (2009) Age 20	N/A	0.77-0.92	0.68-0.82
	Freedman et al. (2007) Ages 5-8	A, B, H, W	0.93	0.94
	Freedman et al. (2007) Ages 9-11	A, B, H, W	0.91	0.92
	Freedman et al. (2007) Ages 12-14	A, B, H, W	0.94	0.92
	Freedman et al. (2007) Ages 15-18	A, B, H, W	0.92	0.88
	Campanozzi et al. (2007) Ages 5-17	N/A	0.93	
	Steinberger et al. (2005) Ages 11-17	N/A	0.93	0.92
	Cameron et al. (2004)	N/A	0.71-0.76	0.74-0.77
	Eisenmann et al. (2004) Ages 3-8	H, W	0.82	
	Dezenberg et al. (1996)	N/A	0.90	
	Gutin et al. (1996)	N/A	0.90	
Hydrodensitometry	Lean et al. (1996) Ages 17-65	W	0.77	0.76
	Deurenberg et al. (1990) Age avg. 11	N/A	0.59	0.61
	Deurenberg et al. (1990) Age avg. 14	N/A	0.73	0.72
	Deurenberg et al. (1990) Age avg. 17.5	N/A	0.74	0.75
	Jackson & Pollock (1977) Ages 18-61	N/A	0.89-0.92	N/A
	Keys et al. (1972) College students	N/A	0.85	N/A
	Keys et al. (1972) Executives	N/A	.82	N/A
	Durnin & Rahaman (1967) Ages 13-16	N/A	0.80	

Race/ethnicity: A - Asian, B - Black, H - Hispanic, W - White.

Advantages

Skinfold thickness measurements provide a safe, noninvasive, portable technique that allows for a more accurate prediction of body fat than does BMI (Brook, 1971; Krebs et al., 2007; Rolland-Cachera, 1993). In particular, the S2SF sites (triceps and subscapular) are generally acceptable to children and adolescents (Hughes et al., 1997). While S2SF does not account for variables (such as age, race/ethnicity, sex, maturation stage, and waist:hip ratio), numerous equations exist that allow for interpretation of the SSF in relation to these variables (Rodriguez et al., 2005; Rolland-Cachera, 1993). According to Nooyens et al. (2007), predicting high body fatness in adulthood is better accomplished via adolescent skinfold thickness than adolescent BMI. Skinfold thickness allows researchers to distinguish between individuals with high body fat versus high body mass (due to lean muscle mass, skeletal composition, etc.), which is critical in regards to the potential negative impact on health status (Himes & Dietz, 1994). Wilmore and Behnke (1970) found very high agreement in percent body fat calculated from a series of skinfold equations, with inter-correlations between $r = 0.999$-1.000. For these reasons, skinfold thickness is widely utilized for large scale obesity screening in children and adolescents.

Disadvantages

Skinfold thickness measurements require skilled technicians in order to correctly identify the skinfold sites, ensure the proper amount of skin and subcutaneous fat is pulled away from the muscle tissue, and accurately record the caliper’s reading (McArdle et al., 2009). Skinfold equations estimate body density from the skinfold measurements, which is then used to estimate body fat. While there are numerous equations for predicting body fat from skinfold thickness, most of these equations are developed from normal weight subjects

(Rolland-Cachera, 1993). Generalized equations developed by Jackson and Pollock (1978) and Jackson, Pollock, and Ward (1980) are based on adult males and females, respectively. Equations to derive percent body fat from body density account for the differences in fat free mass, muscle mass, and skeletal composition in children and adolescents when compared to adults. Children have proportionally less fat free mass mineral content and more water than adults, which results in a lower fat free mass density (Lohman et al., 1984; Lohman, 1986; Boileau et al., 1984). As such, for a given skinfold thickness, children will have a lower body density than adults (Slaughter et al., 1984). By utilizing the specific equation based on the subject characteristics, evaluators avoid the one-size-fits-all pitfall. The use of these equations when evaluating subjects who are obese, or athletic is questionable. Potential errors would include the overestimation of a lean, muscular individual or the underestimation of an obese individual. An extreme example would be the body fat estimate based on skinfold measurement of a sumo wrestler. MRI scans of sumo wrestlers have shown they have relatively little internal fat, with the majority of their fat stores in the subcutaneous layers. As such, skinfold measurements would result in a very high prediction of total body fat, when in fact their fat distribution does not follow the 50% subcutaneous/50% internal fat assumption. In extremely obese subjects, skinfold thickness may exceed the aperture of the caliper’s jaws (McArdle et al., 2009). In addition, obtaining skinfold thickness in extremely lean subjects can be challenging (Eisenmann et al., 2004).

BMI/Skinfold Relationship

Epidemiological assessment necessitates the ability to monitor trends in the spread of obesity (Speiser et al., 2005). As there is presently no consensus on a classification system based on direct measurement of percent body fat in children and adolescents, anthropometric measurements are the predominant measurement tools for studies involving children and adolescents. BMI and S2SF are the two most accessible and cost-effective measures for conducting large-scale obesity screening (Caroli et al., 2007). The CDC 2000 charts allow for reasonably quick and accurate identification of children and adolescents with BMI-for-age >95th percentile who need immediate attention, but may misclassify individuals between the 85th and 95th percentiles (Mei et al., 2007). While BMI does not distinguish between lean body mass and fat mass, it does utilize total body mass, which includes internal fat. Unfortunately, BMI does not distinguish between subcutaneous and visceral fat. Skinfold thickness, while accounting for subcutaneous fat, cannot measure internal fat. The use of S2SF in addition to BMI-for-age significantly increases the accuracy of percent body fat prediction in children and adolescents [resulting in an increase in R^2 from 0.81 to 0.90 in boys and from 0.82 to 0.89 in girls] as well as reducing the overall prediction errors for percent body fat by 20-30% (Freedman et al., 2007). In addition, the combination of BMI and S2SF allows for improved classification of individuals outside of the normal range, such as athletes and obese subjects (Rolland-Cachera, 1993). Each of these two methods has advantages and disadvantages, and each will likely continue to be utilized for large scale screening for the foreseeable future. Therefore, it is important to understand the relationship between BMI and skinfold thickness in order to better interpret results as they relate to each individual. Limited research exists on the relationship between BMI and S2SF, either in children and adolescents, or adults. Table 3 provides an overview of the correlations of BMI with percent body fat, broken down by age, race/ethnicity, and sex when possible.

Table 3. Correlations (r) of S2SF with BMI by ages, race/ethnicity and sex.

Study	*Race/Ethnicity*	*Males*	*Females*
Eisenmann et al. (2004) Ages 3-8	N/A	0.72-0.88	
Revicki & Israel (1986) Ages 20-70	N/A	0.76	
Frisancho & Flegel (1982) Ages 18-74	B W	0.76 0.75	0.76 0.75

Race/ethnicity: B - Black, W - White.

Final Summary

Sum of skinfold thickness better predicts percent body fat, while BMI correlates slightly higher with internal fat and CVD risk factors (Freedman et al., 2007; Jackson et al., 1988; Rolland-Cachera, 1993). A combination of S2SF and BMI allows for differentiation between individuals with high body fat versus high body mass, as well as identification of individuals at-risk for CVD. Ebbeling et al. (2002) identified the clustering of obesity-related CVD risk factors in children as young as age 5. As such, there exists an urgent clinical need to accurately assess adiposity levels in children and adolescents ranging in age from 6-17. The ability to correctly identify excess body fat is improved when using a combination of BMI and S2SF for individuals with a BMI-for-age between the 85th and 95th percentiles (Mei et al., 2007). This percentile range is of particular importance because it applies to children and adolescents classified as *overweight* who may not otherwise receive a physical referral (e.g., individuals with BMI-for-age > 95th percentile are likely large enough that a clinician would not need assistance in determining if they need to make changes to their diet and physical activity levels). S2SF and BMI each have distinct advantages, but when dealing with children and adolescents, a combination of the two measures allows for the most accurate assessment of body composition as well as identification of individuals at-risk for CVD. As such, it is important to understand the relationship between BMI and S2SF in children and adolescents, and to include the effects age, sex, and race/ethnicity have on this relationship.

CHAPTER 3

METHODOLOGY

Research Design

To address the research questions, secondary analyses were performed on data from the 2005-2006 National Health and Nutrition Examination Surveys (NHANES 2005-2006), conducted by the National Center for Health Statistics (NCHS), Centers for Disease Control (CDC). One product of the NHANES is body measurements for the civilian noninstitutionalized U.S. population (McDowell et al., 2005). NHANES 2005-2006 data were released in one, 2-year data set. Utilizing mobile exam centers (MECs), researchers obtained demographic information and anthropometric measurements of height, body mass and skinfold thickness (tricep and subscapular regions) for 5,249 subjects. Subjects aged 16 years and older self-reported race/ethnicity, while a family member reported race/ethnicity for subjects younger than 16 years (Ogden et al., 2008).

Subjects

Subjects for this study consisted of 2,588 males and 2,661 females, for a total of 5,249 subjects. Race/ethnicity breakdown was as follows: Non-Hispanic White 1,447; Non-Hispanic Black 1,894; Mexican American 1,908.

Exclusion Criteria

All subjects were eligible for the body measurement component of the NHANES. Subjects without recorded values for weight, height, and skinfold thicknesses were excluded from statistical analyses.

Instrumentation and Materials

Body Mass

Body mass (BM) was measured using a Toledo electronic weight scale (Mettler-Toledo, Inc., Columbus, OH), supported by the Integrated Survey Information System (ISIS) for accurate data capture. When subjects exceeded the mass capacity of the Toledo scale, BM was measured using Seca digital scales (Seca Corp., Hanover, MD). Mass was measured to the nearest 0.1 kilogram (McDowell, 2005).

Height

Standing height (HT) was obtained using a Seca electronic stadiometer (Seca Corp., Hanover, MD), supported by the Integrated Survey Information System (ISIS) for accurate data capture. Height was measured to the nearest 0.1 centimeter (McDowell et al., 2005).

Skinfold Thickness

Skinfold thickness was measured using Holtain calipers (Holtain Ltd., Crymmych, UK). Skinfold thickness is measured to the nearest 0.1 millimeter following the general procedure outlined by NHANES III Anthropometric Procedures (McDowell et al., 2005; NHANES, 1996).

Procedures

Subject Data Collection

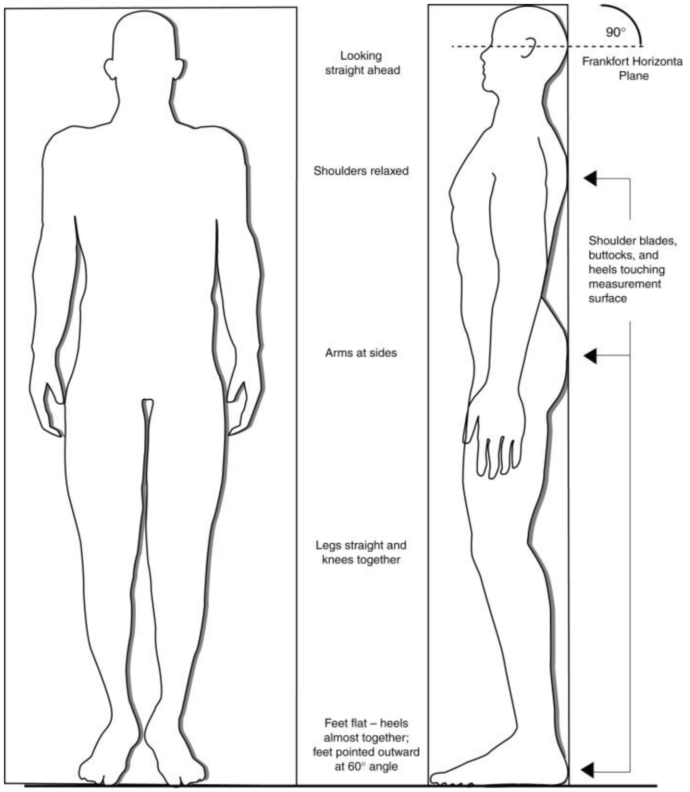
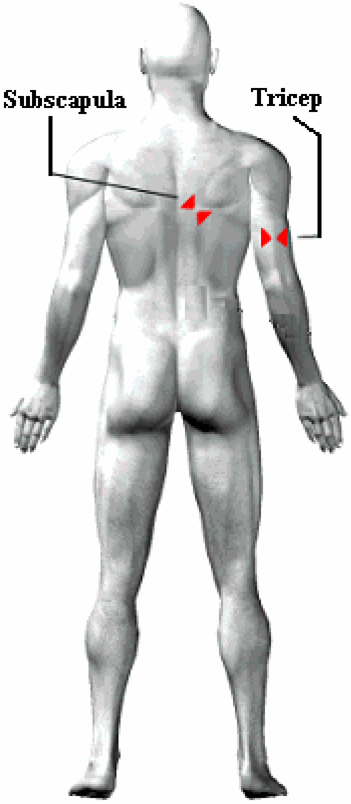
All data was collected in the MECs in accordance with the procedures outlined in the Anthropometry and Physical Activity Monitor Procedures Manual (NHANES, 2005). Measurements that resulted in a value less than the 1st or greater than the 99th percentile for the subject's age and sex triggered the computer to alert the recorder and prompt the examiner to recheck the measurement to ensure it was correct.

Body Mass, Height, and Body Mass Index

BM for most subjects was taken on a Toledo digital scale. BM was measured in pounds and converted to kilograms in the automated system, by a conversion factor of 2.2 (NHANES, 2005). If the subject weighed more than 440 pounds, BM was measured with two Seca digital scales (with one foot on each scale). BM was measured to the nearest 0.1 kilogram.

HT measurements were taken using a "fixed stadiometer with a vertical backboard and movable headboard" (NHANES, 2005). HT was measured to the nearest 0.1 centimeter, in accordance with the guidelines shown in Figure 1.

Figure 1: Guidelines for standing height measurements and skinfold measurement anatomical sites (NHANES, APAMPM, 2005, and adapted from GetFit.121.co.uk, 2007 respectively).

Standing Height Guidelines	Skinfold Measurement Sites
	

BMI was computed from body weight and standing height using the following formula: BMI = Weight / [(Height / 100)^2].

Skinfold Sites

Subjects' skinfolds were measured at two different anatomic body sites: the subscapular and triceps regions (Figure 1). Measurements were taken on the right side of the body unless the subject had "a cast, amputation, or some other reason to avoid measurement on the right side;" when this occurred, measurements were taken on the left side of the body (NHANES, 2005). Marks were made to each site prior to measurements to ensure accuracy over multiple measurements. Independent measurements were taken at each site by two technicians, resulting in a minimum of two skinfold observations for each site. Skinfold thickness was measured to the nearest 0.1 mm. If the difference between the two measurements at a given site was within the pre-specified tolerance limit, no further measurements were taken at that site. The tolerance limits increased by 2 mm for every 10 mm measured. For the first two measures, the first measure represents the base. Thus, from 0-10 mm, observations were acceptable if they differed from the base measurement by ≤ 2 mm; from 10-20 mm, observations were acceptable if they differed from the base measurement by ≤ 4 mm; from 20-30 mm, observations were acceptable if they differed from the base measurement by ≤ 6 mm, and so on. If the difference between the two measurements at a given site did exceed the tolerance limit, each technician repeated and recorded a second measurement, resulting in a total of four measurements at that skinfold site.

Summary skinfold values were computed as follows: If data were available for the third and fourth measurements and the difference between those measurements was within the specified tolerance limit, then the summary value was the mean of the third and fourth measurements. In all other cases, the summary value was the mean of all available measurements at that site. Tolerance was defined using the base skinfold measure, as seen in Figure 2. For the third and fourth measures, the third measure represents the base.

Calibration

The scale, stadiometer, and skinfold calipers were calibrated at the start of each stand. In addition to the calibrations at the start of each stand, the scale was calibrated daily, while the stadiometer and skinfold calipers were calibrated weekly for quality control. The acceptable range for the Toledo electronic scale was 299.75 – 300.25 pounds when weighing six 50.0 pound calibrated weights. The acceptable range for the Seca digital scale was 248.8 – 251.0 pounds when weighing five 50.0 pound calibrated weights. If the scales were outside of the acceptable range, the MEC manager was notified and either a service representative recalibrated the scales, or researchers utilized new scales. The stadiometer was calibrated to read precisely 80 cm for a pre-made calibration rod. Two sets of skinfold calipers were calibrated with four increasing size step wedges, as indicated in Figure 2. If the caliper readings fell outside of the acceptable range at any level, that caliper set was returned to the manufacturer for adjustment, and the alternate caliper set was utilized.

Figure 2: Acceptable ranges for the step wedge readings.

First Step (10 mm)	9.8 – 10.5	Third Step (30 mm)	29.9 – 30.5
Second Step (20 mm)	19.8 – 20.5	Fourth Step (40 mm)	39.8 – 40.4

Data Analysis

All data from the NHANES 2005-2006 survey was examined. Appropriate subject demographics and anthropometric measurements constituted data for entry into PASW (version 17.0, 2009; SPSS Inc, Chicago). Descriptive statistics were calculated for the demographic information collected as follows: total number of subjects at each age group by sex and race/ethnicity; body mass and height by age group, race/ethnicity, and sex. The age groups (6-8, 9-11, 12-14, and 15-17) were chosen based on ANOVA showing no significant differences between 6-8, 9-11, etc.

VARIABLES

Independent Variables

1. Age Group
    a. 6, 7, 8
    b. 9, 10, 11
    c. 12, 13, 14
    d. 15, 16, 17
2. Race/ethnicity
    a. Non-Hispanic White
    b. Non-Hispanic Black
    c. Mexican American
3. Sex
    a. Male
    b. Female

Dependent Variables

1. Body mass index (BMI) (kg/m^2)
2. Sum of two skinfolds (S2SF) (mm)

Statistical Analyses

Multiple linear regression analysis was utilized to investigate the influence of age, sex, and race/ethnicity on the relationship between BMI and S2SF. For the purpose of regression analysis, males were coded as 1, females as 2; Non-Hispanic Whites as 1, Non-Hispanic Blacks as 2, and Mexican-Americans as 3. BMI was set up as the criterion variable, with S2SF, age, sex, and race/ethnicity as the explanatory variables in the following manner, as determined by previous research: BMI = S2SF + age + sex + race/ethnicity. This determined which variables (i.e., age, sex, and race/ethnicity) need to be corrected for when examining the relationship between BMI and S2SF. Multiple linear regression analysis provided information about the influence of sex, and race/ethnicity on the relationship between BMI and S2SF across the previously identified age groups. Potential interaction terms were explored in model development and a forward-backward stepwise selection procedure was applied for the derivation of prediction equation models (Gallagher et al., 2000). Each of the equations was curve-fitted in order to determine differences (e.g., is one linear and another curvilinear, etc.). The function chosen as *best fit* provided the highest R^2 value, regardless of whether there was minimal change when utilizing a more simplified model. Standard error estimates were analyzed to determine the accuracy. R^2 was analyzed to determine how much of the variance in BMI can be accounted for by each of the explanatory variables (S2SF, age, sex, race/ethnicity). Group data was presented as means ± SDs. Due to the large sample size, a *P*-value of 0.01 or less was defined as statistically significant, and was set apriori. All analyses were carried out using the statistical software program PASW (version 17.0, 2009; SPSS Inc, Chicago).

CHAPTER 4

RESULTS

Subject Characteristics

The purpose of this study was to explore the relationship between body mass index (BMI) and sum of triceps and subscapular skinfolds (S2SF). Table 4 provides a summary of the sample size by age group, race/ethnicity, and sex. The total subject pool consisted of 5249 subjects (2588 males and 2661 females) divided into 4 age groups (ages 6-8, 9-11, 12-14, and 15-17). The subject pool included 1447 Non-Hispanic Whites, 1894 Non-Hispanic Blacks, and 1908 Mexican Americans.

Table 4. Subject sample size by age group, race/ethnicity, and sex.

Sex and Race/Ethnicity	Subject Numbers by Age Group				*Total*
	Ages 6-8	Ages 9-11	Ages 12-14	Ages 15-17	
Females					
Non-Hispanic White	200	215	168	166	*749*
Non-Hispanic Black	256	261	223	204	*944*
Mexican American	291	279	224	174	*968*
Subtotal	747	755	615	544	*2661*
Males					
Non-Hispanic White	214	213	139	132	*698*
Non-Hispanic Black	260	299	194	197	*950*
Mexican American	265	281	198	196	*940*
Subtotal	739	793	531	525	*2588*
Total	*1486*	*1548*	*1146*	*1069*	*5249*

Table 5 provides a summary of BMI and sum of skinfolds by age group and race/ethnicity. Analysis of variance for BMI found a significant difference between all age groups ($p < 0.0001$), race/ethnicities ($p < 0.0001$), and sexes ($p < 0.0001$). Mean BMI ranged from 16.4 for Non-Hispanic White females (age group 6-8) to 23.8 for Non-Hispanic Black males (age group 15-17). Mean S2SF ranged from 16.1 for Non-Hispanic Black males (age group 6-8) to 38.0 for Mexican American females (age group 15-17).

Table 5. BMI and S2SF of the four age-groups presented by sex and race/ethnicity.

		Mean BMI		Mean S2SF	
Age[†]	Race/Ethnicity[†]	M[†]	F	M[†]	F
6, 7, 8	*Non-Hispanic White*	16.6 ± 2.7	16.4 ± 3.0	17.1 ± 8.9	19.2 ± 9.9
	Non-Hispanic Black	16.6 ± 2.8	17.1 ± 3.2	16.1 ± 9.2	21.3 ± 11.9
	Mexican American	17.3 ± 3.2	17.1 ± 3.3	18.6 ± 10.5	21.1 ± 10.0
9, 10, 11	*Non-Hispanic White*	18.4 ± 3.2	18.4 ± 3.5	22.3 ± 12.2	25.4 ± 13.6
	Non-Hispanic Black	18.6 ± 3.9	18.9 ± 4.0	20.7 ± 13.0	25.4 ± 13.9
	Mexican American	19.3 ± 4.1	19.4 ± 4.0	23.8 ± 13.3	27.7 ± 13.4
12, 13, 14	*Non-Hispanic White*	20.6 ± 3.9	21.6 ± 4.5	23.3 ± 12.7	31.9 ± 14.1
	Non-Hispanic Black	20.9 ± 4.8	22.5 ± 5.2	22.7 ± 15.8	33.5 ± 17.5
	Mexican American	21.0 ± 4.4	22.1 ± 4.3	24.8 ± 14.3	33.7 ± 13.9
15, 16, 17	*Non-Hispanic White*	22.3 ± 4.0	22.4 ± 3.9	23.8 ± 14.5	35.0 ± 14.2
	Non-Hispanic Black	22.2 ± 3.8	23.8 ± 5.2	20.3 ± 11.3	36.7 ± 17.1
	Mexican American	22.9 ± 4.1	23.5 ± 4.3	24.2 ± 11.5	38.0 ± 14.1

[†] $p < 0.0001$ between all age groups, sexes, and race/ethnicities

Regression Analysis

The results of the BMI regression analyses for all subjects combined are presented in Table 6. First, BMI was regressed on S2SF and a significant effect was found ($p < 0.0001$), with an R square value 0.723; equation yielded: $\text{BMI} = 13.008 + .270*\text{S2SF}$. Second, regressing BMI on S2SF adding race/ethnicity also was significant ($p < 0.0001$), with an R square value 0.724; equation yielded: $\text{BMI} = 12.710 + .270*\text{S2SF} + .147*\text{Race/Ethnicity}$. Adding race/ethnicity to the first equation resulted in a 0.1% increase in the amount of variability in BMI explained. Third, regressing BMI on S2SF adding sex also was significant ($p < 0.0001$), with an R square value 0.748; equation yielded: $\text{BMI} = 14.905 + .283*\text{S2SF} – 1.472*\text{Sex}$. Adding sex into the first equation resulted in a 2.5% increase in the amount of variability in BMI explained. Fourth, regressing BMI on S2SF adding age group also was significant ($p < 0.0001$), with an R square value 0.795; equation yielded: $BMI = 10.921 + .245*S2SF + 1.161*AgeGroup$. Adding age group into the first equation resulted in a 7.2% increase in the amount of variability in BMI explained. Fifth, regressing BMI on S2SF, age group, and race/ethnicity was also significant ($p < 0.0001$), with an R square value 0.796; equation yielded: $BMI = 10.549 + .244*S2SF + 1.164*AgeGroup + .181*Race/Ethnicity$. Adding race/ethnicity into the equation resulted in a 0.1% increase in the amount of variability in BMI explained. Sixth, regressing BMI on S2SF, age group, and sex was also significant ($p < 0.0001$), with an R square value 0.815; equation yielded: $BMI = 12.693 + .257*S2SF + 1.124*AgeGroup – 1.323*Sex$. Adding age group and sex into the equation resulted in a 9.2% increase in the amount of variability in BMI explained. Seventh, regressing BMI on S2SF, age group, race/ethnicity and sex was also significant ($p < 0.0001$), with an R square value 0.815; equation yielded: $BMI = 12.347 + .256*S2SF + 1.127*AgeGroup + .165*Race/Ethnicity -1.318*Sex$. Adding race/ethnicity into the sixth equation resulted in no change in the amount of variability in BMI explained.

Table 6. Regression equations and R^2 of the overall sample.

Regression Variables	$R^{2\dagger}$	Equation
BMI on S2SF	0.723	$\hat{y}$ = 13.008 + .270*S2SF
BMI on S2SF and Race/Ethnicity	0.724	$\hat{y}$ = 12.710 + .270*S2SF + .147*Race/Ethnicity
BMI on S2SF and Sex	0.748	$\hat{y}$ = 14.905 + .283*S2SF – 1.472*Sex
BMI on S2SF and Age Group	0.795	$\hat{y}$ = 10.921 + .245*S2SF + 1.161*AgeGroup
BMI on S2SF, Age Group, and Race/Ethnicity	0.796	$\hat{y}$ = 10.549 + .244*S2SF + 1.164*AgeGroup + .181*Race/Ethnicity
BMI on S2SF, Age Group, and Sex	0.815	$\hat{y}$ = 12.693 + .257*S2SF + 1.124*AgeGroup – 1.323*Sex
BMI on S2SF, Age Group, Race/Ethnicity and Sex	0.815	$\hat{y}$ = 12.347 + .256*S2SF + 1.127*AgeGroup + .165*Race/Ethnicity -1.318*Sex

† $p < 0.0001$ for all regressions
Age Group coded: 1 = Ages 6-8, 2 = Ages 9-11, 3 = Ages 12-14, 4 = Ages 15-17
Race/Ethnicity coded: 1 = Non-Hispanic White, 2 = Non-Hispanic Black, 3 = Mexican American
Sex coded: 1 = male, 2 = female

Table 7. Summary of the R^2 of the four age groups presented by sex and race/ethnicity.

	Non-Hispanic White		*Non-Hispanic Black*		*Mexican American*	
Ages	M	F	M	F	M	F
6, 7, 8	.594	.669	.820	.827	.747	.647
9, 10, 11	.852	.808	.781	.812	.778	.827
12, 13, 14	.697	.814	.740	.851	.815	.814
15, 16, 17	.635	.799	.740	.821	.702	.707

Analysis of the overall R^2 values broken down by age group, sex, and race/ethnicity allows for observations regarding the strength of the relationship of BMI and S2SF (Table 7). Average R^2 values [(M+F)/2] between race/ethnicity classifications were highest in Non-Hispanic Blacks (R^2 = .799), lower for Mexican Americans (avg. = 0.755), and were lowest for Non-Hispanic Whites (avg. = 0.734). Average R^2 values between sexes were highest in Non-Hispanic Black and Non-Hispanic White females (R^2 = .828 and .773 respectively), and least in Mexican American and Non-Hispanic White males (R^2 = .749 and .695 respectively).

Non-Hispanic Whites

In Non-Hispanic White children (Figure 3) there were differences between age groups and sexes; males data best fit a linear function, and females data best fit either linear (ages 6-8) or polynomial (ages 9-11) equations. In Non-Hispanic White adolescents (Figure 4) there were differences between age groups and sexes; males data best fit a linear function, and females data best fit either linear (ages 12-14) or polynomial (ages 15-17) equations.

Figure 3. Comparison of the relationships between S2SF and BMI in Non-Hispanic White children presented by sex.

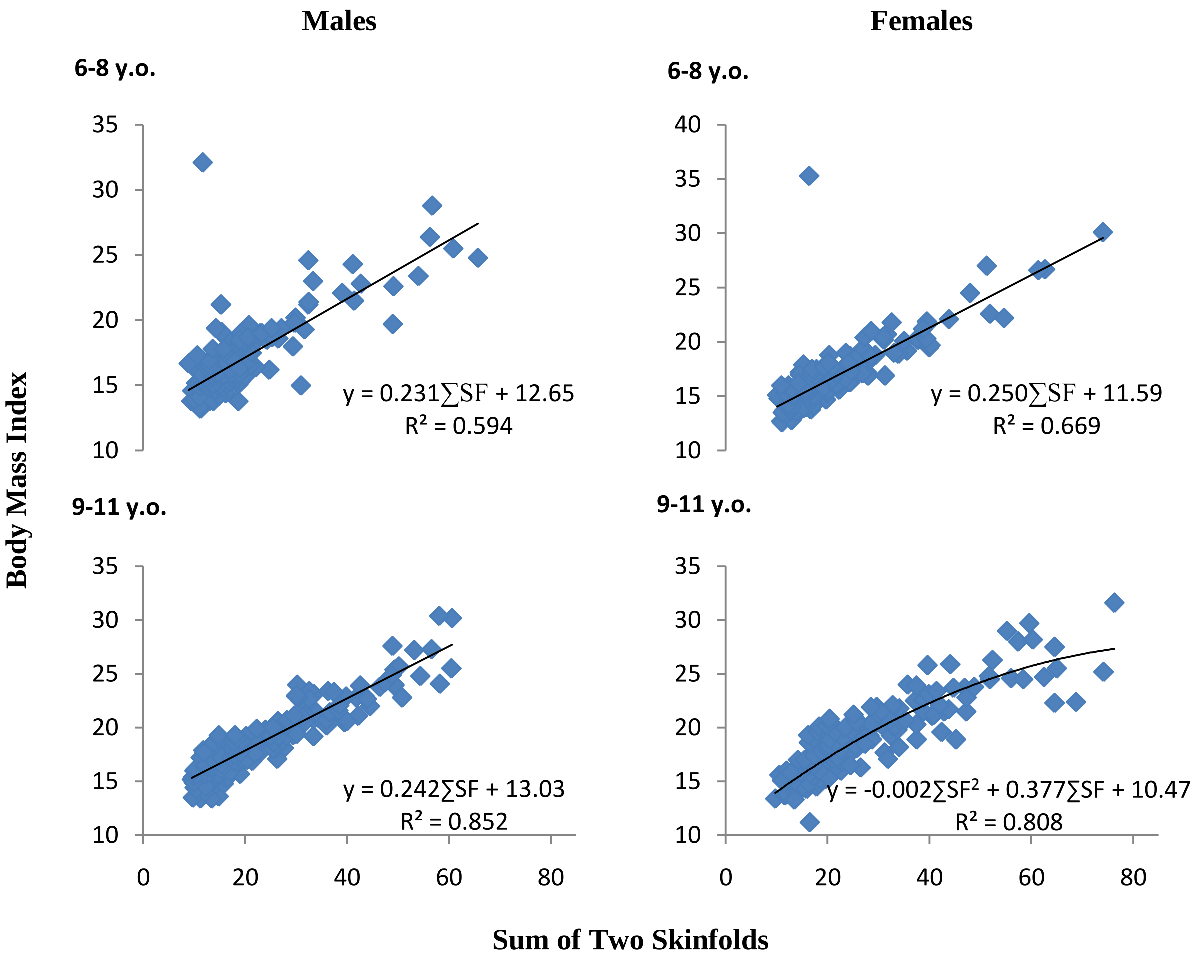
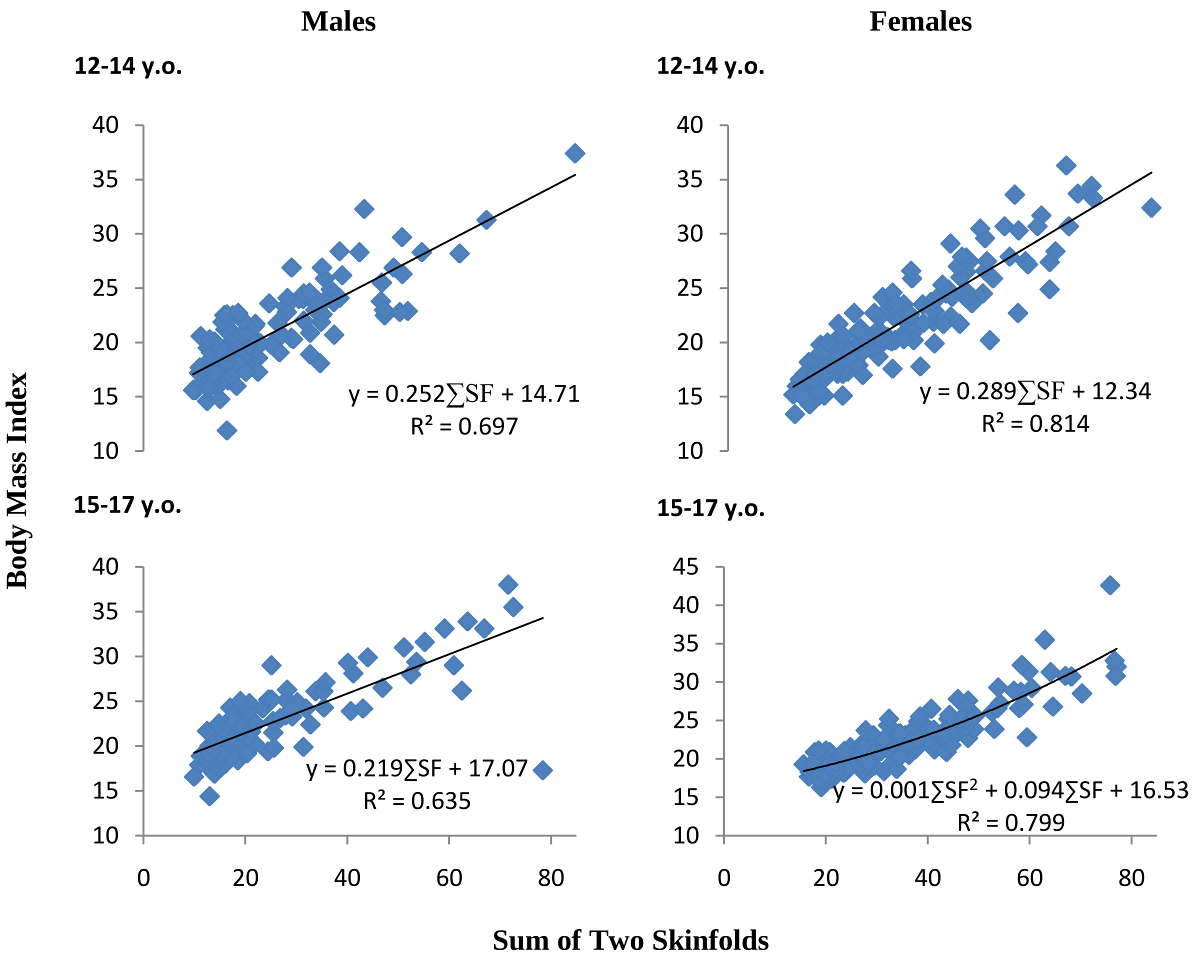


Figure 4. Comparison of the relationships between S2SF and BMI in Non-Hispanic White adolescents presented by sex.



Non-Hispanic Blacks

In Non-Hispanic Black children (Figure 5) there were differences between sexes but not age groups; males data best fit a linear function, while females data best fit a polynomial function. In Non-Hispanic Black adolescents (Figure 6) there were differences between age groups and sexes; males data best fit either polynomial (ages 12-14) or linear (ages 15-17) equations, and females data best fit either linear (ages 12-14) or polynomial (ages 15-17) equations.

Figure 5. Comparison of the relationships between S2SF and BMI in Non-Hispanic Black children presented by sex.

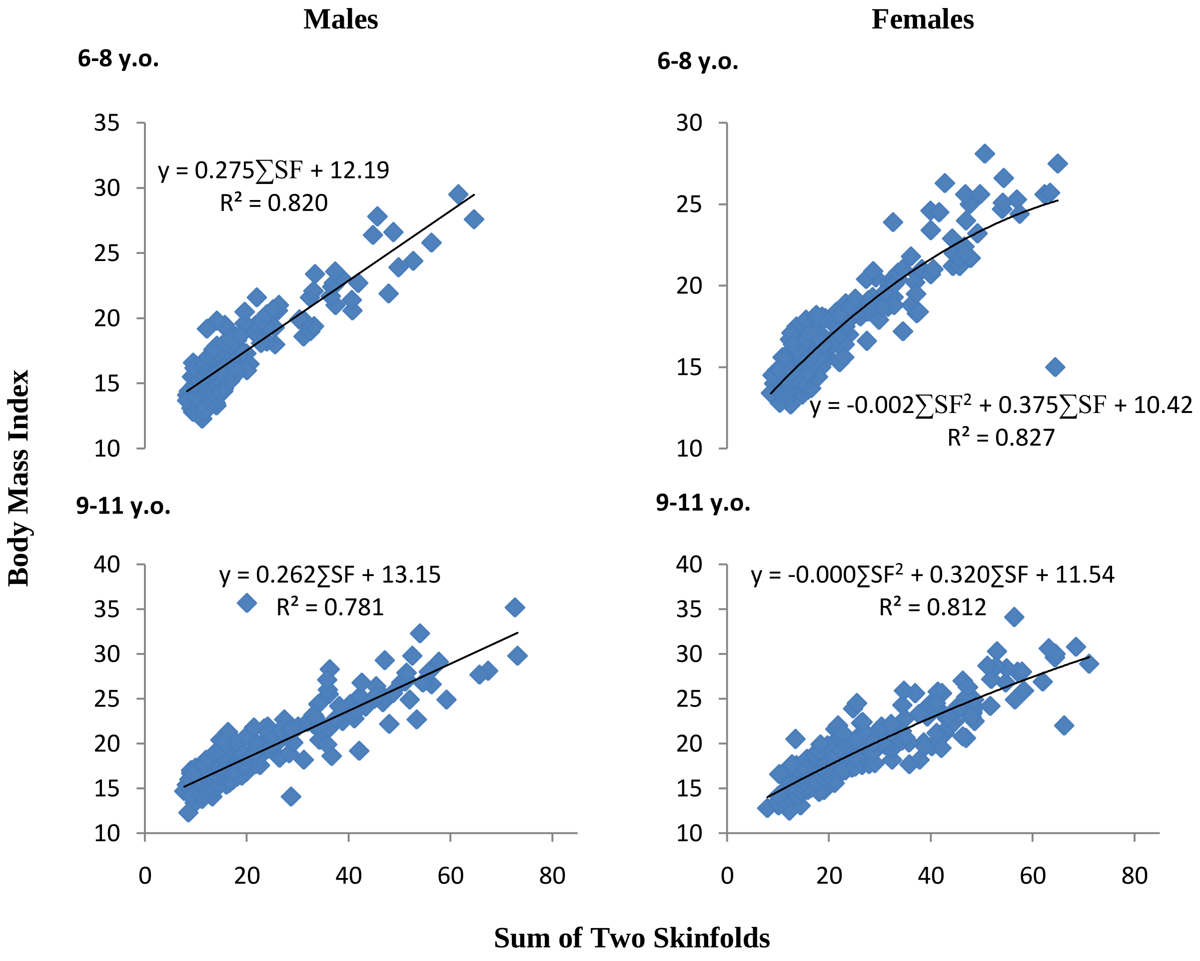
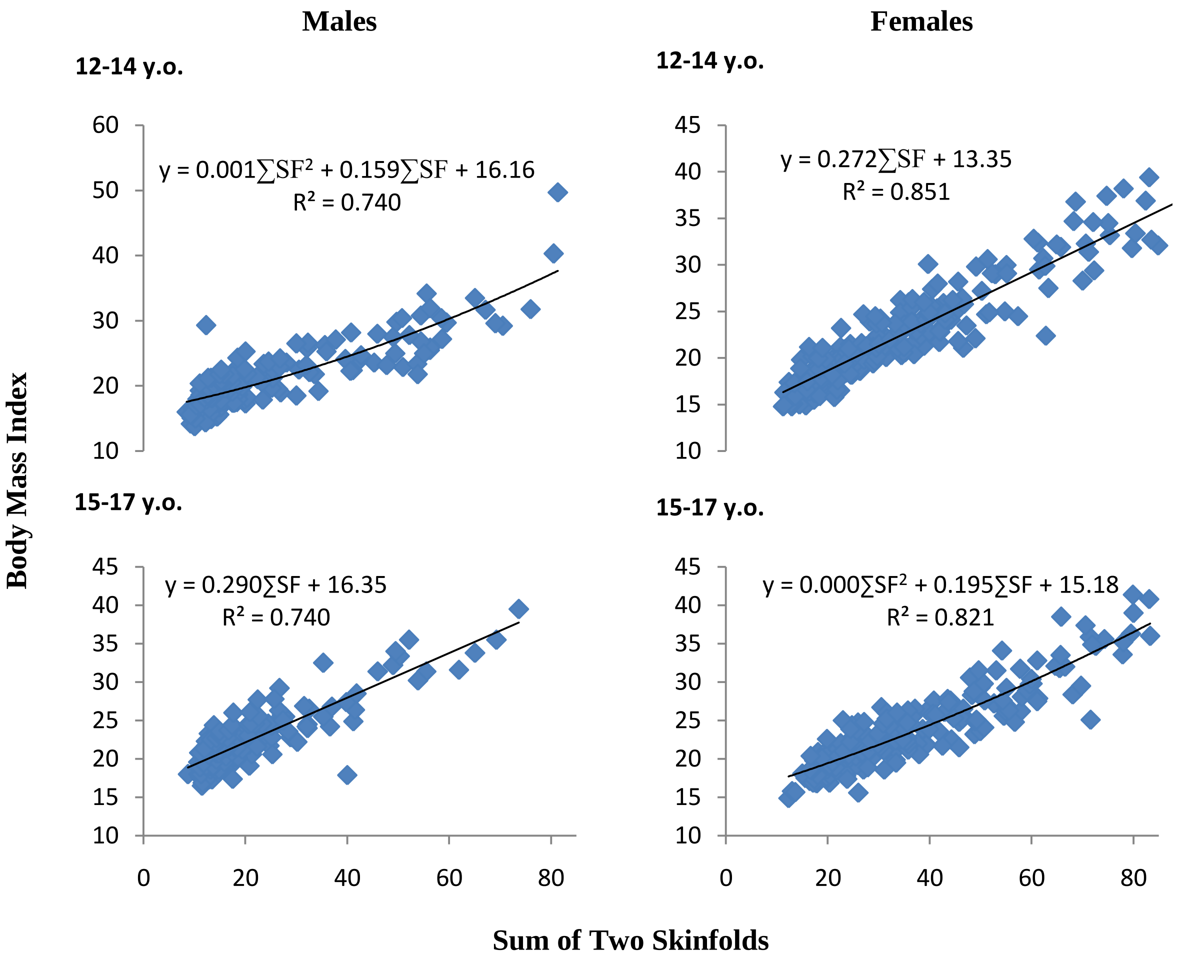


Figure 6. Comparison of the relationships between S2SF and BMI in Non-Hispanic Black adolescents presented by sex.



Mexican Americans

In Mexican American children (Figure 7) there were differences between age groups in males, as well as between sexes; males data best fit either linear (ages 6-8) or exponential (ages 9-11) equations, and females data best fit a power equation. In Mexican American adolescents (Figure 8) there were differences between age groups in females, as well as between sexes; males data best fit a linear function, and females data best fit either linear (ages 12-14) or exponential (ages 15-17) equations.

Figure 7. Comparison of the relationships between S2SF and BMI in Mexican American children presented by sex.

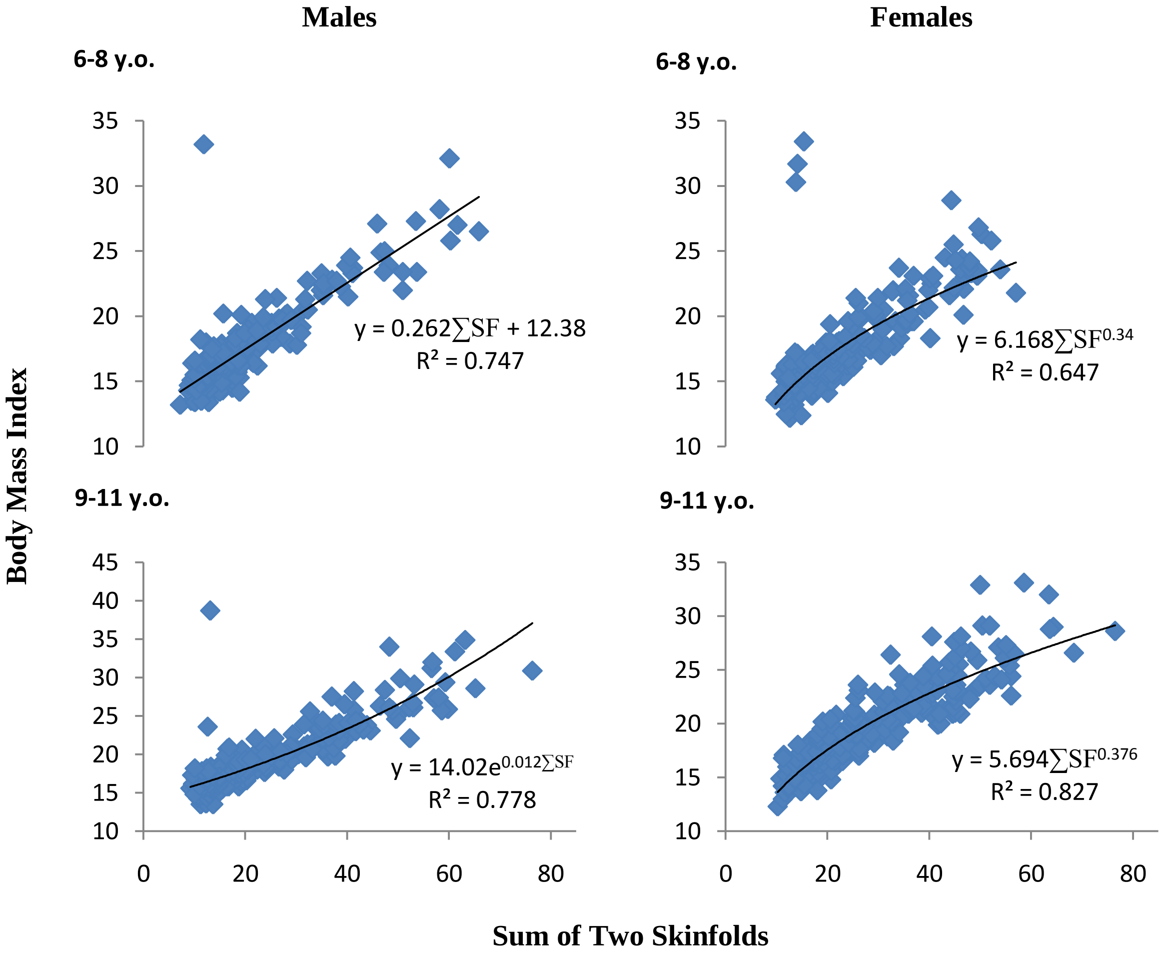
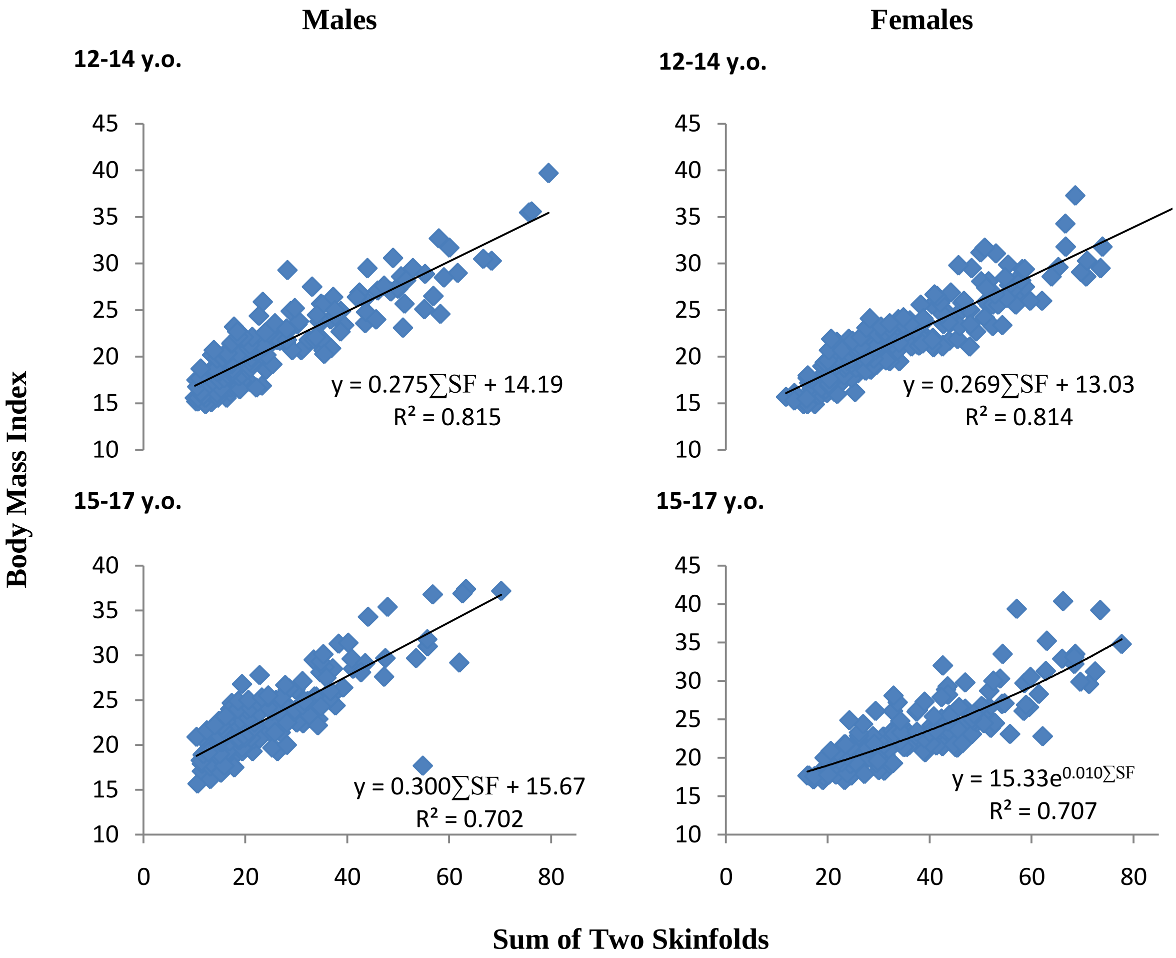


Figure 8. Comparison of the relationships between S2SF and BMI in Mexican American adolescents presented by sex.



CHAPTER 5

DISCUSSION

Introduction

The results of this study indicate that the relationship between body mass index and sum of triceps and subscapular skinfolds varies according to age group, sex, and race/ethnicity. This is in agreement with previous findings that indicate age, sex, and race/ethnicity influence body composition (Freedman et al., 2008; Soh et al., 2009; Daniels et al., 1997). The relationships were very strong, statistically, regardless of the age group, sex, or race/ethnicity classification. Linear relationships were fairly consistent with males, but relationships varied widely with females. This is in contrast to previous findings in adults, both male and female, where the function is curvilinear and the best fit is often accomplished using power or logarithmic functions (Gallagher et al., 2000). This section will provide a discussion of the statistical analysis, the strengths and limitations of this study, summary conclusions, clinical relevance of the findings, review of research hypotheses, and recommendations for future research.

Regression Analysis

Regressing BMI on S2SF, age group, and race/ethnicity resulted in an increasing amount of variation in BMI accounted for when moving from S2SF to the combination of S2SF and age group, with race/ethnicity providing minimal contribution to the relationship. A similar study by Gallagher et al. (1996), examined the relationship between BMI and percent body fat, yielding similar results (i.e., significant age group and sex dependencies observed in the BMI/percent body fat relationship).

Each of the equations was curve-fitted in order to determine differences (e.g., is one linear and another curvilinear, etc.). If the goal had been to develop prediction equations, choosing a linear fit for each model would have simplified the process, resulting in a slight reduction in the R^2 value. Average decrease in R^2 value, that would result due to a change from best fit to linear, is as follows: Non-Hispanic White females (0.015); Non-Hispanic Black males ages 12-14 (0.006); Non-Hispanic Black females (0.007); Mexican American males ages 9-11 (0.024); and Mexican American females (0.027). The purpose of this study was to examine the relationship between BMI and S2SF, therefore the line chosen as *best fit* provided the *highest* R^2 value, regardless of whether there was minimal change when utilizing a more simplified model (i.e., linear).

Qualitative interpretation of R^2 values adhered to the following guidelines: .81-1.00 = very high; .49-.80 = high, .25-.48 = moderate; .07-.24 = low; .00-.06 = little, if any. The overall R^2 values (Table 7) for the four age groups ranged from high to very high, meaning that nearly all the variation in BMI is associated with S2SF for all age groups, race/ethnicities, and sexes. Non-Hispanic White 6-8 year old males had the lowest R^2 value (R^2 = 0.594), while Non-Hispanic White 9-11 year old males had the highest R^2 value (R^2 = 0.852). In both Non-Hispanic White and Mexican American children, R^2 was higher for 9-11 year olds than for 6-8 year olds in both males and females. The opposite was true in Non-Hispanic Black children, where R^2 was higher for 6-8 year olds than for 9-11 year olds in both males and females. In adolescents, R^2 was higher for 12-14 year olds than for 15-17 year olds in all race/ethnicities, with the exception of Non-Hispanic Black males, in which R^2 remained the same from 12-17 years of age.

Breakdown of BMI versus sex and S2SF versus sex resulted in statistically significant ($p < 0.0001$) differences between males and females. The regression equations for most males followed a trend towards linear, with the exception of Non-Hispanic Black 12-14 year old males (polynomial) and Mexican American 9-11 year old males (exponential). This is in contrast to research on adults, where males trend towards curvilinear (Gallagher et al., 2000). The contrast is likely due to the physiological and chemical changes taking place in children and adolescents as they grow in stature and develop (Rolland-Cachera, 1993). The slopes for the linear relationships in Non-Hispanic White males ranged from 0.22-0.25, while those for both Non-Hispanic Black and Mexican American males ranged from 0.26-0.29. This data suggests that, in males, Non-Hispanic Whites have a lesser change in S2SF with each unit change in BMI when compared to Non-Hispanic Black and Mexican American males. A similar comparison for females is difficult due to the varying regression equations, where only four of the age groups followed a linear trend.

Examination of BMI versus race/ethnicity resulted in statistically significant ($p < 0.0001$) differences between each of the race/ethnicities. Table 5 provides an overview of mean values for BMI and S2SF by race/ethnicity and age group. Subjects categorized as Mexican Americans had the highest mean BMI, followed by subjects categorized as Non-Hispanic Blacks and Non-Hispanic Whites, respectively. There exists a steady, although not entirely linear, increase in BMI with increasing age. Analysis of BMI versus age groups results in statistically significant ($p < 0.0001$) differences between each of the four age groups. Subjects in group Ages 6-8 had the lowest mean BMIs, followed by subjects in groups Ages 9-11, Ages 12-14, and Ages 15-17 respectively. This continuous increase in BMI with age is similar to the growth pattern seen in percent body fat in adults, where Gallagher and colleagues (2000) demonstrated that as adults age, BMI and percent body fat increase in a similar fashion (up to a BMI of ~30). In male adolescents, however, percent body fat peaks during ages 12-14, and then decreases through age 18 before climbing again (Dai et al., 2002). The continual increase in the BMI and S2SF of females with age is in agreement with previous research findings (Dai et al., 2002).

Mean values for BMI and S2SF increased with age, with two notable exceptions (Table 5). The S2SF for Non-Hispanic Black and Mexican American males peaked in the 12-14 year old age group, and decreased in the 15-17 year old age group, while BMI values continued to increase. These findings are in agreement with those of Dai and colleagues (2002) during their examination of the growth patterns of S2SF and BMI. There is an inverse relationship between changes in S2SF and BMI provides evidence that S2SF is perhaps a better standard to use in classification for children and adolescents as overweight or obese. Skinfold thickness is a more direct measure of actual body fat than BMI, and due to the inverse relationship between changes in S2SF and BMI, subjects with a decreasing body fat (S2SF) are receiving increasing BMI scores. The fact that BMI increases despite a decrease in subcutaneous fat composition, and thus a decrease in percent body fat, potentially leads to a misclassification error. Therefore, during adolescence in race/ethnicities of Non-Hispanic White, Non-Hispanic Black, and Mexican American, S2SF is perhaps a better standard to use in classification of weight status.

Strengths and Limitations

Strengths of this study include the large sample size (5249 subjects), the stringent data collection protocols followed by the NHANES, and the straightforward statistical analysis. The NHANES draws a sample that is representative of the US population, meaning that the results can be generalized to the broader US population that falls within the ages of 6-17 and the Non-Hispanic White, Non-Hispanic Black, and Mexican American race/ethnicities. A weakness may include the inability to obtain data from every subject in the 2005-2006 NHANES due to missing data points in one or more of the variables being examined. A limitation may include the use of multiple RAs obtaining skinfold thickness data, however the NHANES protocols are very strict and control for variance as much as possible.

Conclusions

Overall, there were significant differences in the relationship between BMI and S2SF by age, race/ethnicity and sex. While S2SF alone accounts for 72.3% of the variation in BMI, adding sex (+2.5%) and age (+7.2%) as explanatory variables increases the variability accounted for to 81.5% (Table 5). Adding race/ethnicity (+.1%) results in no clinically relevant change when age and sex are already accounted for, so race/ethnicity may not play as great a role in children, although possibly in adolescents, as it does in adults. Age is the largest contributor, followed by sex, with race/ethnicity contributing little to the relationship.

The relationship between BMI and S2SF within sex is somewhat variable based on age group. The data for males best fit a linear function, with only two exceptions: Non-Hispanic Black males ages 12-14 and Mexican American males ages 9-11 (Figures 3-8). The data for females showed no consistency, ranging from linear to polynomial to power to exponential functions (Figures 3-8).

BMI is not as good a surrogate for percent body fat as S2SF in children and adolescents. The changes in growth and development taking place from ages 6-17 pose significant obstacles for BMI, an index of height and body mass. BMI provides reasonably accurate assessment of body fat individuals in the highest percentiles (≥95th percentile BMI-for-age), but does not adequately assess children and adolescents in the lower percentiles. S2SF provides more accurate assessment of body fat than does BMI, is equally precise when performed by a trained technician, and is equally correlated with CVD risk factors.

Review of Hypotheses

Based on the results, the following hypotheses we accept or fail to accept. The first hypothesis stated that the relationship between BMI and S2SF would be positive, but curvilinear. The 24 regression models were all positive, but varied in mathematical function, requiring “a failure to accept” this hypothesis. The second hypothesis stated that the correlation between BMI and S2SF would decrease with increasing age. The correlations peaked at various age-groups, but never at the highest age-group, requiring “a failure to accept” this hypothesis. The third hypothesis stated that the correlation between BMI and S2SF would be greatest for Non-Hispanic Blacks, would decrease for Mexican Americans, and be least for Non-Hispanic Whites. The correlations were highest for Non-Hispanic Blacks (avg. = 0.799), decreased for Mexican Americans (avg. = 0.755), and were least for Non-Hispanic Whites (avg. = 0.734), requiring “acceptance” of this hypothesis. The fourth hypothesis stated that the correlation between BMI and S2SF would be greater for females than for males. Correlations were generally higher for the females than males, requiring “acceptance” of this hypothesis (Table 7, Figures 3-8). Based on these findings, it can be concluded that: the relationship between BMI and S2SF is positive, but varies in function across age-groups, race/ethnicities, and sexes; the correlation between BMI and S2SF varies independently with age and sex; and the correlation between BMI and S2SF is greatest in Non-Hispanic Blacks, lower for Mexican Americans, and is weakest for Non-Hispanic Whites.

Clinical Relevance

Large scale obesity screening for children and adolescents will continue to incorporate BMI and possibly S2SF for the foreseeable future. As such, it is important to understand the relationship between these two methods of measuring body composition. In addition, the results suggest that while variations in age group and sex account for a large percentage of change in BMI and S2SF, race/ethnicity has a minimal effect on the relationship. As such, race/ethnicity may not be a critical variable when conducting BMI and S2SF screening in children and adolescents in the US. A combination of the two methods may prove to be the most useful for clinicians. BMI allows for a quick, easy to repeat measurement tool for early identification of individuals who may require intervention. Children and adolescents with high BMI-for-age could then be followed up with skinfold measurements to assess body fat distribution and gauge the necessity for further treatment.

Recommendations

If the BMI percentile scores were available, it would have been interesting to explore the distribution across the age groups and race/ethnicities by sex. Future studies might consider a longitudinal examination of this same relationship (BMI versus S2SF) across the lifespan, rather than a snapshot glimpse at children and adolescents. In addition, it would be advantageous to perform a similar study using a greater percentage of obese children and adolescents (as identified by BMI > 95th percentile) for comparison purposes. Determining the S2SF at the 85th and 95th percentiles by age and sex would allow for a more in-depth interpretation as well. In the long-term, there exists a need to develop a classification system based on percent body fat. These changes would allow for interpretation as to which children and adolescents might be at greater risk for becoming overweight or obese, thus allowing health care providers an opportunity to intervene at a younger age, prior to the damaging effects of obesity.

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