COMPARISON OF BODY COMPOSITION BY DUAL-ENERGY X-RAY ABSORTIOMETRY AND BIOELECTRICAL IMPEDANCE IN OBESE INDIVIDUALS: A SUBANALYSIS OF THE INSIGHT WEIGHT LOSS STUDY

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TABLE OF CONTENTS

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ABSTRACT

Measuring changes in body composition in obese individuals is crucial to understanding the differential impact of weight loss interventions. Dual-energy x-ray absorptiometry (DEXA) has emerged as the method of choice to measure body composition due to its ability to differentiate fat, lean and bone mass, and its ability to measure whole body and regional components with minimal participant burden. However, use of traditional whole body DEXA scan technology to measure body composition of obese individuals is limited by the manufacturer's upper weight specification and the scanning area of the instrument. To obtain valid whole body DEXA measurements, subjects must weigh less than 200 to 350 pounds, depending on make and model of the DEXA scanner, and fit completely within the scanning area of the instrument (6'3" by 2'1"). One way to accommodate a greater portion of the obese population is to develop an alternative method to scan subjects who meet the weight criteria but exceed the width of the scanning area, such as the regional half-body DEXA scan analysis.

This prospective cross-sectional study compared body composition parameters measured by whole and half-body DEXA scan analyses and bioelectrical impedance analysis (BIA) in ninety-eight obese adults who weighed less than the manufacturer's upper weight limit and who fit completely within the DEXA scanning area. Body composition parameters measured by half-body DEXA scan analysis were multiplied by two to compare to parameters measured by whole body DEXA scan analysis. Body composition parameters measured by each technique were compared using paired t-tests, linear regression models, and Bland and Altman's method for limits of agreement.

Participants had an average weight and body mass index of 103 ± 13 kg and 36 ± 4 kg/m^2, respectively. The mean difference for fat mass was lower (0.23 kg; $p < 0.005$) and the mean difference for lean mass was higher (0.42 kg; $p < 0.001$) when analyzed by the right half-body DEXA method than the whole body DEXA method. Mean differences for fat mass and lean mass were higher (0.65 kg; $p < 0.001$ and 0.45 kg; $p < 0.001$, respectively), when analyzed by the left half-body DEXA method than the whole body DEXA method. Fat-free mass (lean mass plus bone mass) was lower (1.85 kg; $p < 0.001$) and fat mass was higher (2.31 kg; $p < 0.001$) by BIA than by whole body DEXA analysis.

In this sample of obese participants, differences in body composition parameters measured by whole and half-body DEXA analyses, although statistically significant, are not considered clinically different. These results suggest that half-body DEXA scan analysis is a reasonable alternative to whole body DEXA analysis when subjects meet the weight criteria but do not fit within the scanning area. Mean differences in body composition parameters measured by whole body DEXA analysis and BIA were larger than the mean differences between whole and half-body DEXA analyses but these differences are still considered to be small. Therefore, using BIA with gender and body-fat specific prediction equations to calculate body composition parameters in obese individuals is a reasonable alternative when DEXA technology is not available.

SIGNIFICANCE

It is estimated that over 64% of adults in the US are overweight and that 30% are obese (1 - 3). This means that over 60 million American adults are obese as defined by a BMI >30 kg/m^2, and approximately 9 million adults are morbidly obese as defined by BMI>40 kg/m ^{2} (4). This major public health problem is associated with over 30 medical conditions, which include multiple forms of cancer, diabetes mellitus, and cardiovascular disease. Obesity now ranks second among all causes of preventable death, second only to tobacco-related deaths, and contributes to about 112,000 excess deaths per year (5). The public health and medical communities have responded to the recent obesity epidemic by implementing initiatives that promote healthier food choices and more active lifestyles (6). The research community is supporting these efforts by studying the differential impact of various interventions on short- and long-term weight loss and maintenance of weight loss, changes in body composition, body fat deposition and the impact on morbidity and mortality (2, 7 - 14).

Two technologies are commonly used to assess body composition in population-based studies: dual energy X-ray absoptiometry (DEXA) and bioelectrical impedance analysis BIA (15). Dual energy X-ray absoptiometry (DEXA) a 3 compartment model based on differential tissue attenuation of X-rays, has emerged as the research technique of choice for measuring body composition because of its ability to distinguish total and regional lean mass, fat mass, and bone mass, and because of its minimal participant burden. However, DEXA methodology is limited in that it requires that subjects weigh less than the manufacturer's maximum weight limit, often values less than 200-350 pounds, and to fit completely within the scanning area, limiting height to less than 6'3"

and recumbent width to 25 inches. To accommodate those who meet the weight criteria but do not fit within the scanning area, an alternative half-body DEXA scan analysis method is proposed. If validated, this analytical technique will allow DEXA technology to be used to measure fat, lean and bone mass in a greater proportion of obese individuals.

Bioelectrical impedance analysis (BIA), a two-compartment model based on total body water content and the differential water content of fat tissue and fat-free tissue (the sum of lean mass plus bone mass) is also available to assess body composition. While BIA technology is not limited by an individual's weight or physical dimensions, it too has methodological limitations. Accuracy of measurements of body composition in obese individuals by BIA is affected by the use of proprietary prediction equations derived from regression models developed from healthy, normal-weight individuals. Accuracy is also affected by an individual's hydration status and by assumptions that water content in fat-free and fat tissue of obese individuals is the same as in normal weight individuals (1, 16 - 18). If body composition measured by BIA is not different from that measured by whole body DEXA scan analyses, BIA may be an appropriate method to use when DEXA technology is not an option.

SPECIFIC AIMS

The primary specific aim of this study was to compare fat mass and lean mass measured by whole body and half body DEXA analyses in obese, weight stable but otherwise healthy adults.

The secondary aim was to compare fat mass and fat-free mass measured by whole body DEXA analysis and BIA.

The tertiary aim was to explore variables – age, weight, height, gender and BMI - that may predict differences in body composition methods.

HYPOTHESES

The hypotheses that were tested are:

- Fat mass and lean mass have a mean difference equal to or less than 1 kg when measured by whole body DEXA scan analysis and the left and right half-body DEXA scan analyses.
- Fat mass and fat-free mass have a mean difference equal to or less than 1 kg when measured by whole body DEXA scan analysis and BIA.

OBESITY CHAPTER

The Obesity Epidemic in the United States

Obesity is diagnosed when an individual has excess body fat (19). It is chronic, relapsing, stigmatizing, and a neurochemical disease that is associated with energy imbalance (20). Obesity is one of the most common nutritional disorders in western societies and the rate of obesity in the United States (US) is rising across all regional and demographic segments.

Results from the 1999 to 2000 National Health and Nutrition Examination Survey suggest that an estimated 64% of US adults are either overweight or obese (19). The prevalence of obesity as defined by a BMI $\geq$30 kg/m^2 has increased 3-fold in the past 4 decades (1 - 3). The prevalence of obesity in the pediatric population is also increasing and may predict even higher rates of morbidity and mortality associated with obesity in the US in future years (4).

Health risks associated with obesity continue to emerge and are reflected in the healthcare system (3). Obesity is the leading cause of morbidity, as it is associated with an increase in risk for certain cancers, as well as increased risk for diabetes mellitus Type 2, cardiovascular disease and stroke, hypertension, renal disease, and disability (3, 4). Many of these conditions can be reversed or improved with modest weight loss of 5-10% of an individual's body weight (20). With the increase in rates of obesity, obesity-related disorders and health problems, comes an increase in healthcare costs (3). Annual healthcare costs for obese Americans are estimated to be around $100 billion (3). In the US, obesity ranks second among all causes of preventable death (3) and contributes to approximately 112,000 excess deaths each year (5).

Identifying Obesity

One population-based tool that is used to screen for obesity is the body mass index (BMI). BMI is calculated by dividing an individual's weight in kilograms by their height squared in meters (kg/m^2). Adults with a BMI between 25 and 29.9 kg/m^2 are considered overweight, while adults with a BMI of 30 kg/m^2 or greater (19) are considered obese. The degree of obesity is further categorized into three classes. Class I obesity is defined as a BMI 30-34.9 kg/m^2, class II obesity is defined as a BMI of 35-39.9 kg/m^2, and class III obesity is defined as a BMI equal to or greater than 40 kg/m^2 (19).

Energy Balance Model

Obesity is a metabolic disease that does not occur quickly. In most cases obesity develops over relatively long periods of time and is caused by the interaction of multiple genetic and environmental factors. Among these are excessive energy and food intake, decreased physical activity, behavioral factors and genetic predisposition leading to individual metabolic and counter regulatory response to weight loss. The defining feature of obesity is excess body fat stores that develop as cumulative energy intake exceeds energy expenditure or "positive energy balance". The underlying principle of the energy balance model is governed by the first law of thermodynamics that states, "Energy is neither created nor destroyed". Simply illustrated, energy balance is defined by the equation:

$$\text{Energy Balance} = \text{Energy}_{\text{Intake}} - \text{Energy}_{\text{Expenditure}}$$
$$\text{or}$$
$$\text{Energy}_{\text{In}} = \text{Energy}_{\text{Out}}$$

When applied to body weight regulation, energy balance is attained when energy intake equals total energy expenditure and body stores of energy, fat stores, are stable. An individual is in positive energy balance when energy intake exceeds total energy expenditure and body energy stores increase. Conversely, an individual is in negative energy balance when energy intake is less than total energy expenditure and body energy stores decrease.

BODY COMPOSITION CHAPTER

An individual's body composition reflects his or her ability to accumulate and store nutrients and substrates from their environment (21). Various components of the human body give rise to structure and function. For example, both muscle and bone provide structure and shape as well as allow the body to move and react. Fat stores provide a source of insulation and protection as well as energy in times of deprivation and release hormones in response to physiological change.

Human bodies are comprised of three primary components: fat mass, lean mass, and bone mass (21). Fat mass includes the fat stored as triglyceride in adipose tissue and fat associated with other tissues in the body. Lean mass is comprised of extracellular and intracellular fluids, total body protein, carbohydrates and soft tissue minerals. Bone mass refers to the mineral content of bone tissue. Taken together, lean mass and bone mass are referred to as fat-free mass. Levels of each body composition component that fall below or rise above normal ranges are associated with specific health risks. For this reason, it is important that researchers and clinicians be able to measure and interpret an individual's body composition and changes in body composition associated with various weight loss interventions and their associated changes morbidity or mortality.

The relationship between body composition and risk of morbidity and mortality is affected by a number of physical and environmental factors (Table 1).

Table 1. Factors that Affect the Relationship between Body Composition and Risk of Disease and Death (21).

FACTORS	
Biological factors	Age Sex Genetic susceptibility Ethnicity or race Menopausal status
Milieu	Sociocultural factors Physical environment Economic factors
Lifestyle factors	Past and current smoking habits Quality and quantity of dietary intake Alcohol consumption Physical activity
Health-related factors	Background prevalence of disease Genetic disposition to disease Presence of diabetes Presence of other risk factors
Biometric factors	Height (including history of stunting and wasting) Fat and muscle distribution Body proportions (e.g., leg length, sitting height) History of large weight fluctuation

Body Fat Content

Millions of adipocytes comprise the fat mass and adipose tissue within the adult body. Adipocytes produce hormones, prohormones, cytokines and enzymes, as well as store triglycerides (21, 22). When there are increased levels of fat mass, there is also an increase in proteins produced by the adipocytes, which can result in health problems. Excess fat mass is associated with low-grade inflammation of adipose tissue. Macrophages infiltrate adipose tissue, which results in the overproduction of the pro-inflammatory cytokines, tumor necrosis factor (TNF-α) and interleukin (IL-6) (23). TNF-α and IL-6 can alter insulin sensitivity by triggering steps in the insulin-signaling pathway, and can lead to diabetes (23).

Body Fat Distribution

The distribution of body fat stores plays a significant role in disease development. Distribution of fat in the abdominal region is associated with a greater risk of cardiovascular disease than distribution of fat around the hips and thighs, or gluteofemoral area (24). In postmenopausal women, increased trunk fat is reported to be a strong predictor of insulin resistance and dyslipidemia, as well as hyperinsulinemia (12, 25). Increased waist circumference is reported to be an accurate portrayal of visceral adiposity. Waist circumference $\geq$ 82 cm in women and $\geq$ 102 cm in men is associated with increased risk for compromised health that is exacerbated by increased BMI as presented in Table 2 (19).

Table 2. Increased disease risk associated with increased waist circumference and BMI (19, 21).

			Disease Risk (Relative to Normal Weight and Waist Circumference)	
	BMI (kg/m^2)	Obesity class	Men <102 cm, Women <88cm	Men >102 cm, Women >88cm
Underweight	<18.5		---	---
Normal	18.5-24.9		---	---
Overweight	25.0-29.9		Increased	High
Obese	30.0-34.9	1	High	Very high
	35.0-39.9	2	Very high	Very high
Extremely obese	>40	3	Extremely high	Extremely high

Lahmann and colleagues (26) studied adiposity in relation to mortality in 10,902 men and 16,814 women living in Malmo, Sweden, excluding only those who had a lack of Swedish language skills. The men and women were each divided into two age-specific groups for the analysis. The first group of men was 46 – 59 years old, and the second group was 60 - 73 years old. The women were grouped in similar age ranges. Percent body fat measurements and their relative risk for death were analyzed in quintiles. Researchers reported that increased fatness was associated with higher risk for mortality in middle-aged women compared to a lower risk of mortality in older women. The fifth quintile of percent body fat had a 1.96-increased risk of mortality in the middle-aged women. The opposite was seen in men, with the increased risk of mortality seen in the older group.

Similar findings were reported by Bigaard and colleagues (11) in a study of 57,053 Danish men and women. A J-shaped relationship was observed with fat mass and all-cause mortality. This suggests that the risk for all-cause mortality is slightly higher in individuals with very low fat mass levels, minimal in individuals with normal fat mass levels, and higher in individuals with higher fat mass levels.

Fat-Free Mass

Fat-free mass is another component of body composition and is comprised of two sub-compartments, lean mass and bone mass, with muscle mass making up a largest proportion of fat-free mass. Fat-free mass is made up of approximately 73 % water and has a high electrolyte content. The amount of fat-free mass is closely related to basal metabolic rate. Fat-free mass is the more metabolically active tissue, particularly the tissue that makes up body organs, which contributes to increased metabolic rate (27 - 29). Energy expenditure may appear to be higher in obese individuals compared to lean individuals when analyzing absolute fat-free mass. However, after adjusting for differences in lean mass, there are no differences in metabolic rate between obese and lean individuals (28). Fat-free mass can differ between ethnicities. African-Americans have denser lean mass (1.113 g/cm^3) than Caucasian Americans (1.100 g/cm^3), despite nearly identical height, weight and total body water content (30). Researchers suggested it was due to the larger bone mineral content in African-Americans than Caucasian Americans.

Bone Mineral Content & Bone Mineral Density

Bone health is an important health issue, especially in the elderly, making measurement of bone mineral content and bone mineral density key parameters that are commonly assessed. Bone quality is assessed by measuring bone mineral content (g), bone area (cm^2), and bone mineral density (g/cm^2), all of which can be measured by dual-energy X-ray absorptiometry (DEXA). Total bone mineral content is estimated from ash weight post-mortum analyses and in adults comprises 4-5% of total body mass. This

range in percentage is similar to total body bone mineral content measured by DEXA (21, 31).

Gender and ethnicity influence bone quality. African Americans have higher bone mineral content and bone mineral density than American Caucasians in all stages of life (21, 31 - 33). Bone mineral density is higher for males than for females in both ethnic groups (21, 32, 34) and bone mineral density decreases with age within all ethnic groups.

Glauber and colleagues (35) analyzed 6,705 older women in a prospective multi-center study. Within each cohort, they found that fat mass had a higher impact on bone mineral density at non-weight bearing sites, whereas overall body mass had a greater impact on bone mineral density at weight bearing sites. The researchers suggested that the direct effects of gravitational forces and mechanical or loading effects of excess weight on the skeleton account for the effect of weight on bone density. Adiposity effected weight, thereby contributing to the weight-bone mineral density relationship.

Health Interpretation of Body Composition Parameters

As with obesity, fat and lean mass are associated with increased risks for morbidity and mortality (7). Past research has provided information about theoretical body composition ranges. As shown in Table 3, the 70 kg reference male is comprised of 15% total fat, 44.8% muscle mass, and 14.9% bone mass, where as the 58 kg reference female is comprised of 25% total fat, 38% muscle and 12% bone mass (24, 36). The healthy range for percent body fat is 20-25% for females and 12-15% for males based on bioimpedance (24, 36). Very few studies have reported cut-off points for percent body

fat (37). The World Health Organization (WHO) defines excess body fat as >25% body fat for males and >35% for females (38).

Table 3. Reference Caucasian Man and Woman (21).

	Unit	Reference Man	Reference Woman
Body Mass (BM)	kg	70	58
Body Height	cm	170	160
Body Surface Area	cm^2	18,000	16,000
Water Content	ml/kg BM	600	500
Extracellular	ml/kg BM	260	200
Intracellular	ml/kg BM	340	300
Total Body Fat	kg	13.5	16.0
Total Body Adipose Tissue	kg	15.0	19.0
Subcutaneous Adipose Tissue	kg	7.5	13.0
Dry Skeletal Weight	kg	5.0	3.4
Total Body Skin	kg	2.60	1.79
Skeletal Muscle	kg	28	17
Spleen	g	180	150
Heart	g	330	240
Stomach	g	150	140
Liver	g	1800	1400
Pancreas	g	100	85
Lung	g	1000	800
Kidneys	g	310	275
Uterus	g	---	80
Both Breasts	g	26	360
Brain	g	1400	1200
Spinal Cord	g	30	28

Body composition reflects nutritional status and ultimately the state of energy balance. Being able to assess body composition assists health care providers with nutritional assessments and can be a tool to provide better care (39). Changes in an individual's weight and relative body composition can provide insight into the efficacy of different weight loss programs (2, 40).

BODY COMPOSITION TECHNIQUES CHAPTER

Multiple techniques based on different technologies are used to assess body composition. As illustrated in Table 4, most techniques have been developed and validated throughout the last century. The first techniques measured urinary nitrogen and analyzed cadavers by estimating gross composition based on physical and chemical analysis, and became the reference techniques (29). Further research produced techniques that measured body density, total body water, and total body potassium. The mathematical models and concepts for bioelectrical impedance analysis were developed and introduced in the earlier part of the century, but the prototypes for the bioelectrical impedance analyzers currently used were not developed until 1962, and commercial models were not available until the mid-1980's (21). More advanced imaging methods like dual-energy x-ray absorptiometry (DEXA), magnetic resonance imaging (MRI) and computer tomography (CT) were developed shortly after. CT was first reported in 1972, but its use in body composition analysis did not occur until 1979 (21). This technology not only changed body composition research, but diagnostic medicine as well. CT technology and the mathematical models associated with it, paved the way for MRI. Dual-photon absorptiometry (DPA) developed in 1984 led to the development of DEXA in 1987 (21, 42).

Validated tools currently used to assess body composition include, but are not limited to, DEXA, BIA, air displacement plethysmography and hydrostatic weighing. Hydrostatic weighing, also known as under-water weighing, is based on Archimedes Principle that a body completely immersed in water is acted on by a buoyancy force, that

Table 4. Body composition research events (21).

Year	Event
1850s	Justus von Liebig found human body contains many substances present in food and that body fluids contain more sodium and less potassium than tissues.
1859	J. Moleschott first reported values for the amounts of protein, fat, extractives, salts and water per 1,000 parts of the human body.
1906	A. Magnus-Levy announced for the first time the concept of fat-free mass.
1907	E.P. Cathcart found that nitrogen was lost from the body during fasting.
1909	P.A. Shaffer and W. Coleman used urinary creatinine excretion as an index of muscle mass.
1916	D. Du Bois and E.F. Du Bois proposed a height-weight equation to estimate whole body surface area.
1921	J. Matiegka derived an anthropometric model to estimate total body muscle mass.
1934	G. von Hevesy and E. Hofer used deuterium to estimate total body water volume.
1940	H.C. Stuart, P. Hill and C. Shaw first used two dimensional standard radiography to estimate bone, adipose tissue, and skeletal muscle shadows.
1942	A.R. Behnke, Jr., B.G. Feen, and W.C. Welham estimated the relative proportion of lean and fat mass in the human body based on Archimedes Principle.
1943	J. Nyboer developed and applied tetrapolar bioimpedance analysis (BIA) to evaluate fluid compartments.
1945	N. Pace and E.N. Rathbun found the relatively constant ratio of total body water to fat-free body mass and suggested a method for estimating body fat from total body water.
1945	H.H. Mitchell, T.S. Hamilton, F.R. Steggerda and H.W. Bean first reported whole body composition analysis on the molecular level (water, fat, protein, ash, Ca and P) for an adult human cadaver.
1951	E.M. Widdowson, R.A. McCance, and C.M. Spray first reported whole body composition analysis on the atomic level (Ca, P, K, Na, Mg, Fe, Cu, and Zn) for adult human cadavers.
1953	A. Keys and J. Brozek provided a detailed analysis of the densitometric technique.
1953	A. Keys and his colleagues carried out the classic Minnesota Experiment and traced the effects of semi-starvation and refeeding on body components in young male volunteers.
1955	N. Lifson, G. B. Gordon and R. McClintock measured total body water and total body carbon dioxide production by using $D_2{}^{18}O$ dilution method.
1958	R. Kulwich, L. Feinstein and E.C. Anderson and W. Langham reported the existence of a correlation between natural ^{40}K concentration and fat-free body mass.
1960	J.M. Foy and H. Schneider determined total body water by using the tritium dilution method.
1961	W.E. Siri developed a three-component model to estimate total body fat mass.

1961	G.B. Forbes, J. Hursh, and J. Gallup estimated fat and lean contents by using whole body ^{40}K counting.
1962	A. Thomasset introduced the BIA method.
1963	J.A. Sorenson and J.R. Cameron developed the theoretical basis of dual-photon absorptiometry (DPA) for body composition.
1970	R.B. Mazess, J.R. Cameron and J.A. Sorenson developed DPA method for peripheral body composition in vivo.
1972	G.N. Hounsfield reports the first computerized tomographic imaging system that revolutionizes clinical medicine and body composition research.
1978	Selinger developed a four-component model and equation.
1979	S.B. Heymsfield, R.P. Olafson, M.H. Kutner, and D.W. Nixon first used computed axial tomography for body composition analysis.
1983	CT was used in whole body composition analysis (G.A. Borkan et al 1983; K. Tokunaga et al 1983, and L. Sjostrom et al 1986).
1984	M.A. Foster, J.M.S. Hutchison, J.R. Mallard and M. Fuller were among the first to demonstrate that magnetic resonance imaging (MRI) could accurately measure body composition.
1984	R.B. Mazess, W.W. Peppler and M. Gibbons developed DPA for total body composition measurements.
1987	Dual-energy X-ray absorptiometry (DEXA), a four compartment model, is developed. (42)
1990	S.B. Heymsfield and colleagues estimated appendicular skeletal muscle by dual-energy x-ray absorptiometry (DEXA).
1991	J.J. Kehayias and colleagues developed a method for assessing total body fat mass from total body carbon mass by in vivo neutron activation analysis.
1992	Z.M. Wang, R.N. Pierson, Jr., and S.B. Heymsfield proposed the five-level model of human body composition.
1992-2003	DEXA and BIA systems proliferated worldwide and were incorporated into many ongoing research and clinical programs.
1992-2003	Air displacement plethysmography (Bod Pod) was developed and commercialized, providing an alternative to the older and less practical underwater weighing method.

creates a "loss" of body weight equal to the weight of water displaced by the body. The weight of the water displaced can be used to calculate the volume of water displaced and thus the volume of the submerged body. The volume of the body (BV) is equivalent to the weight "lost," corrected for the density of water (1 gm/cc); therefore body volume equals the dry weight on land (Wa) minus the weight in water (Ww) divided by the density of water (Dw); BV = [(Wa – Ww)/Dw] (21). The density of the submerged body can then be calculated with the following formula: weight on land divided by the

difference between the weight on land and weight in water divided by the density of water, and then subtracting the residual lung volume plus 0.1.

$$Db = Wa / [\{(Wa - Ww)/Dw\} - (RV + 0.1)].$$

Percent body fat can be calculated from body density (g/cm^3) using the Siri equation (43) [Body Fat (%) = {(4.95/Density) – 4.50} * 100].

Densitometry (2-compartment models)

Hydrostatic weighing is considered the standard or reference technique for body composition assessment, but it, too, has limitations. For this measurement to be performed accurately, individuals must be comfortable submerged underwater, while expelling as much air from their lungs as possible and remaining as still as possible until the weight measurement is read and recorded. Under some conditions, the extremely obese cannot fit within the water tank used for this procedure. At the same time obese participants must own, and be comfortable wearing, a tight-form-fitting bathing suit and swim cap during the procedure. It is also difficult and sometimes impossible for populations like young children, the elderly, or the disabled to perform this method of body composition measurement.

Air displacement plethysmography was developed using similar principles as hydrostatic weighing. However, this body composition method uses Poisson's laws of pressure-volume relationships to calculate body volume and density. For a known volume of 300 L and pressure within the reference chamber, and a known pressure applied by an oscillating membrane in the test chamber, the unknown volume of the body of an individual can be calculated (21). This procedure requires that temperature and

humidity remain constant, and accuracy and precision are impacted by differences in temperature or humidity in the air next to the individual's skin and hair. Because air close to the body is also more compressible than the air in the rest of the chamber individuals must wear tight, form-fitting clothing (e.g., a lycra bathing suit and a hair cap) during this procedure. This method uses the same equation, the Siri equation, as hydrostatic weighing to calculate body composition.

Air displacement plethysmography differs from hydrostatic weighing in that it does not require the individual to get wet or to hold their breath and remain calm while submerged underwater. For these reasons, air displacement plethysmography may be a more acceptable method for analyzing body composition of children, the elderly, the infirm or disabled individuals. Air displacement plethysmography shares similar disadvantages with hydrostatic weighing. Participants are required to wear tight form-fitting clothing, remain as still as possible in a small, enclosed area and properly exhale into a device that measures residual lung volume. However, these limitations do not ease the difficulty in measuring individuals who are obese. Finding tight, form-fitting clothing can be difficult and the individuals must weigh less than 500 pounds. With a test chamber volume of approximately 0.45 cubic meters, obese individuals usually do not fit comfortably within this enclosed space.

Bioelectrical Impedance Analysis (A Two Compartment Model)

Bioelectrical impedance analysis (BIA) is an easy, safe, convenient, inexpensive and non-invasive technique used to assess body composition (39). The method assumes that the body behaves as a cylindrical conductor of electricity (41). BIA measures the

resistance or electrical conductivity of body tissues with an alternating electrical current at a very low and safe amperage to determine body composition (21, 44). Electrical conductivity through the body is dependent upon the tissue's water and electrolyte content (39). Electrical current flows differently through extracellular and intracellular water compartments with different frequencies. When frequencies are ≤5 kHz, the current flows through the extracellular water compartment. However, as frequencies increase, the electrical current flows through the intracellular water space as well. At frequencies above 100 kHz, the electrical current flows equally through all body tissues. Many studies use a single frequency analyzer, with a 50 kHz frequency (21, 44).

Because fat tissue and fat-free tissue have different water contents they also have different electrical conductivity properties. Fat tissue has a relatively low water and electrolyte content, and thus fat tissue is less conductive of an electrical current (18). Adipose tissue contains about 14% water and is completely free of potassium (45). Fat-free tissue has a water content of 72-74%, and approximately 50-70 mmol/kg of potassium depending on gender (45).

One problem associated with BIA technology is the use of a few proprietary predictive equations to calculate fat-free mass for all individuals no matter the age, ethnicity, or BMI (2). These prediction equations are based upon data from a healthy, normal weight population and use the assumption that fat-free mass is approximately 73% water (21, 44). Therefore, to apply these equations to individuals outside this population may not be appropriate (46). Since this method is based on body water content, individuals with edema, chronic renal insufficiency, and obesity, conditions that may present with altered hydration status, may not be accurately analyzed by

bioelectrical impedance (18). Under- and over-estimation of fat-free mass in the elderly as well as underestimation of fat-free mass in women compared to other methods has been reported (1). Obese individuals have large alterations in body compartments compared to non-obese individuals with an increase in total body hydration and a larger extracellular water volume compared to intracellular water volume (47). Also, obese individuals tend to have more trunk mass, which invalidates the assumption that the body is cylindrical (41). Therefore, underestimation of fat mass and overestimation of fat-free mass is often reported when BIA is used to measure body composition in obese individuals when compared to DEXA (18, 42, 47, 48).

For populations outside of the healthy population, alternative BIA equations have been validated to calculate fat-free mass. To be validated, these equations were compared to another validated body composition method (21). Therefore, the validated equation is only as accurate as the comparison method used to determine the dependent variable in the equation. For example, to calculate body composition in obese individuals, Segal et al developed gender and body fat specific equations (17). These regression equations include the BIA measured bioresistance and the individual's weight (kg), height (cm), and age (yrs) to calculate fat-free mass. Hydrostatic weighing was used to calculate body fat and fat-free mass, which were included as the dependent variables in the linear regression analysis. Therefore, this equation is limited to the accuracy of the hydrostatic weighing procedure and the Siri equation used to calculate body fat by this method.

Dual-Energy X-Ray Absorptiometry (A Three Compartment Model)

Dual-energy X-ray absorptiometry (DEXA) analysis was developed and initially used to assess bone quality in postmenopausal women as a means to diagnose osteoporosis (49). DEXA uses x-ray technology to scan an individual's body and relay the imaging information to a computer software program for analysis. DEXA machines measure the amount of passable radiation that is pulsed from a "K-edge" filtered X-ray tube through various body tissues (23, 50, 51). This X-ray filter generates two energy peaks from a single X-ray beam. Attenuation of the X-ray strength occurs as a result of the physical interactions that take place between the tissues and the photons (a quantum of radiant energy) and results in reduced beam intensity, which is a function of tissue composition. Attenuation at the lower energy peak (45 meV) relative to the higher energy peak (100 meV) enables DEXA software to differentiate soft tissue as either lean or fat tissue (21, 52).

Older models of DEXA scanners use pencil beam x-ray absorptiometry, where the X-ray beam moves along a rectilinear path. Newer models of DEXA scanners use fan beam x-ray absorptiometry, which allows larger portions of the body to be scanned at one time reducing the scanning time of a whole body scan. For example, the QDR-1000/W scanner (Hologic Inc, Bedford, MA), a pencil beam scanner, completes a whole body scan in 10 to 20 minutes, where as a QDR 4500W scanner (Hologic Inc, Bedford, MA), a fan beam scanner completes a whole body scan in 3 to 5 minutes (53). Shorter scan times are associated with less x-ray exposure to the participant so that the total radiation dose for a whole body scan with the QDR 1000/W pencil beam scanner is 1.0 mRem compared to 0.3 mRem with the QDR 4500W fan beam scanner. Fan beam models have

improved geometrical resolution, but it has also been noted that these models have errors with fan beam magnification when measuring tissues with increased thickness (50). Within the types of fan beam models, there is limited-angle fan beam absorptiometry and true fan beam absorptiometry. Limited-angle fan beam models are less accurate and less precise, and have poorer image resolution than true fan beam absorptiometry models (50).

Different DEXA models have different scan velocities. As seen with scan type (pencil beam versus fan beam), the velocity of the scan can produce varying degrees of accuracy. For example, the Lunar DPX-IQ DXA scanner has three scan modes: slow, medium and fast scan mode. The manufacturer recommendations are to use different modes with varying degrees of trunk thickness. The fast mode should be used when scanning an individual with a trunk thickness between 15 – 22 cm, the medium mode should be used when scanning an individual with a trunk thickness between 22-28 cm and the 28 slow mode should be used when scanning an individual with a trunk thickness of >28 cm (54). When using the Lunar model, the preferable mode is the slow mode which produces the most accurate results when measuring fat mass, lean mass, bone mineral content and body mass (54). Consistent scan velocity within and between scans is also crucial for achieving precise body composition measurements over the duration of a study (55).

DEXA computer software generates an image based upon the X-ray scan, which displays the individual's body and differentiates fat mass, lean mass and bone mass. The computer analysis program measures the differential amount of fat, lean and bone mass in grams by the amount of X-ray absorbed by the tissues. Due to its ability to assess

multiple components of body composition, DEXA has been used and is currently used in studies for analysis of body composition of individuals of all ages, both sexes, and a variety of health conditions and body sizes (2, 11, 40, 46, 48, 49, 56).

DEXA technology is based on four assumptions. The first assumption is that there is a constant attenuation of pure fat and bone mineral-free lean tissue, which is used to estimate the fat content in soft tissue (21, 57). DEXA measures the proportion of fat mass and lean mass in each pixel, which means that DEXA measures fat as a unit of measurement rather than fat as a component of adipose tissue. In actuality, the attenuation of fat has small variation from person to person (21, 51). The second assumption is that body compartment measurements are not affected by the anteroposterior thickness of the body. The impact of body thickness is minimal for those who have a body thickness ≤ 20 cm. However, body thickness ≥ 25 cm is associated with greater error in body composition measurement due to less attenuation measured by DEXA (21, 58, 59). For this reason, there tends to be a more accurate measurement of body fat in the lower extremities where there is less tissue than in the trunk of the body (60, 61). The third assumption is that the fat content of the area analyzed is associated with fat content of the area not analyzed. About 40-45% of the 21,000 pixels analyzed in a whole body scan contain bone as well as soft tissue (lean and fat mass), and, as a result, they are excluded from the calculation for soft tissues. A fourth assumption is that each region of the body is equally represented per unit volume in the total body analysis. For instance, DEXA has difficulty differentiating soft tissue and bone in the thorax due to the spine and ribs blocking the X-ray and reducing attenuation by the time it reaches the

thorax. For that reason, underestimation may occur in body regions where there are larger areas of bone such as the arm and thorax (52).

Despite these limitations, DEXA is considered the method of choice for analyzing body composition in the obese population (2). While DEXA machines are expensive, more facilities are purchasing DEXA machines so that more researchers have access to using them. This technique can be accurate and precise, reasonably quick, yield minimal radiation exposure (equivalent radiation exposure as a cross country flight), differentiate bone, muscle and fat mass, and provide whole and regional body composition assessments (18, 62). Individuals do not have to get wet or be comfortable underwater to complete the measurement as with hydrostatic weighing, and they do not have to correctly expel all of the air out of their lungs to measure residual lung volume as with hydrostatic weighing and air displacement plethysmography.

Kiebzak and colleagues (55) determined coefficient of variations for fat mass, lean mass, bone mineral content and body fat percentage in DEXA. Ten men and ten women, 24-76 years old, were measured daily for four consecutive days using a Lunar DPX-L DEXA scanner. Participants weighed on average 158 ± 23 lbs and had a mean BMI of 24.7 ± 2.5 kg/m^2. Coefficients of variation were reported to be 2.0%, 1.11%, 1.10%, and 1.89% respectively when using DEXA to measure body composition.

One general disadvantage in using DEXA for research is the use of a variety of DEXA models and software versions. The advancement in technology has benefited the accuracy of body composition measurements by DEXA, but has led to the generation of inconsistent data due to technological variations between models and software programs. Consequently, use of various DEXA models and software versions has made validation

of this technique quite difficult, as one model and software program may be validated against a reference technique, but another model may not. An example of this is in a study by Litaker and colleagues (53). The researchers compared a Hologic QDR-1000/W pencil beam scanner, to the Hologic QDR 4500W fan beam scanner. Participants were scanned three times, once with the QDR 1000/W model and twice with the QDR 4500W model. There was poor agreement in body composition parameters between the QDR 1000/W and QDR 4500W scans compared to the duplicate scans with the QDR 4500W. Therefore, there can be less precision between different models, even when they are made by the same manufacturer. As a result of this analysis, it is imperative that when DEXA analysis is performed, the same model and software version should be used to obtain maximum accuracy.

One key limitation of DEXA technology is that the DEXA scanning table does not accommodate everyone. DEXA machines have a manufacturers' weight limit of 200 pounds for older models and 350 pounds for newer models, so those individuals who exceed these weight limits cannot be analyzed with this method (1). In addition, despite meeting the weight criteria, some obese adults do not fit within the 190 x 60 cm 2-dimensional scanning area, so that accurate body composition analysis from a whole body scan cannot be obtained from this population. Accuracy of this technique decreases as body size increases. DEXA is very sensitive to body thickness, resulting in overestimation of body fat in those who have thicker abdomens (21, 46, 63). Furthermore, individuals must remain motionless and lay flat during the scanning process, which can be uncomfortable for many people, especially those who experience breathing difficulties when in a recumbent position for an extended period of time (18).

Lastly, DEXA is not a portable method. Individuals must travel to a site where DEXA is available and researchers must find a study site that has a DEXA machine if this technique is chosen as the study's body composition method of choice.

Alternative DEXA Analysis

Only one study by Tataranni and Ravussin in 1995 has offered a solution for scanning obese individuals who exceed the scanning area but otherwise meet the weight and height criteria for DEXA. In this study, two DEXA scans were performed in 27 individuals who did not fit within the DEXA scanning area, one of the right half of the body and one of the left half of the body, using a pencil beam DEXA machine. The data from the left and right half body scans were added together and compared to total body composition parameters measured by hydrodensiometry. Six of these 27 individuals could not complete the study because of extreme discomfort while lying down on the DEXA table; four other participants could not perform the hydrodensiometry procedure. Correlations, mean differences, and limits of agreement using the Bland-Altman method were calculated for half-body DEXA and hydrodensiometry measurements. The participants were 30 ± 7 years old, 170.5 ± 9.5 cm tall, weighed 75.0 ± 11.9 kg, and had a BMI of 25.8 ± 4.1 kg/m^2. There were small differences in body composition parameters between the left and right half DEXA analyses and correlation coefficients were greater than 0.96 for each body composition parameter. The mean difference between the right and left half-body DEXA scan analyses for percent body fat was 0.3 ± 1%, and the mean difference for fat mass was 0.72 ± 0.11 kg. There was a 0.03 ± 0.11 kg mean difference between the right and left half-body DEXA analyses for fat-free mass and a mean

difference of 0.03 ± 0.09 kg for bone mineral content. The sum of the right half-body DEXA analysis and the left half-body DEXA analysis body composition parameters were not significantly different from those determined by hydrodensiometry. Percent body fat calculated by the half-body DEXA measurements was 2% higher than that calculated by hydrodensiometry. Fat-free mass was 3.3 kg lower by the sum of the half-body DEXA measurements than hydrodensiometry, while fat mass was 1.4 kg higher by the sum of half-body DEXA measurements than hydrodensiometry. The error in predicting body composition by half-body DEXA scans compared to hydrodensiometry were not affected by the subject's body size and/or scanning technique. These researchers concluded that the results from half-body scans accurately predicted whole body composition compartments.

Comparison of Techniques

Studies have shown a lack of agreement in body composition parameters between DEXA and BIA techniques in obese individuals. Erselcan and colleagues (18) performed a cross-sectional study measuring the agreement between BIA and DEXA in 16 non-obese and 21 obese women. BIA underestimated fat mass by 1.7 kg and 1.6 kg in obese and nonobese women, respectively, compared to DEXA. The researchers also observed large limits of agreements between DEXA and BIA when measuring fat mass in the obese women, and concluded that there was poor agreement between the two methods when measuring obese individuals.

Kyle and colleagues (64) studied healthy adults, 65 men and 61 women, to compare the accuracy of measuring fat-free mass by DEXA, BIA and total body

potassium, which uses a radioactive isotope (^{40}K) to indirectly measure fat-free mass. The study used two different equations to calculate body composition for both BIA (RJL Systems Inc., 17) and total body potassium (65, 66). Compared to BIA (17) and total body potassium measurements (66), DEXA underestimated fat-free mass by 3.5 kg and 3.2 kg, respectively, in women but not men. DEXA also overestimated fat mass compared to BIA and total body potassium in men but not in women. These researchers stated that this was due to a higher proportion of fat mass in women than men.

Bolanowski and Nilsson (1) analyzed lean mass, fat mass and percent body fat in 59 women and 41 men by DEXA (Lunar DXP-L) and BIA. The men had a mean BMI of 22.3 ± 3.3 kg/m^2 and the women had a mean BMI of 24.5 ± 4.6 kg/m^2. Compared to DEXA, lean mass was overestimated by 3.8 ± 1 kg in men and 6.5 ± 2 kg in women when measured by BIA and fat mass was underestimated by 1.7 ± 1.7 kg in men and 4.5 ± 2.4 kg in women. The study also found highly significant correlations between lean mass, fat mass and percent body fat measured by DEXA and BIA.

Das and colleagues (2) concluded that DEXA underestimated lean mass and overestimated body fat when compared to BIA, after massive weight loss in obese individuals who had undergone gastric bypass surgery (2). These authors suggest using a 3-compartment model that combines air displacement plethysmography to measure fat and fat-free mass with BIA to measure total body water when studying the obese individuals and deemed traditional reference methods to be inaccurate for extremely obese individuals (2). While multiple studies have compared different techniques of body composition measurement, very few have included obese subjects in the analysis

due to limitations of the equipment and the difficulty in obtaining accurate measurements in this population.

Importance of Body Composition Methods for Measuring Obese Individuals

The rising rates of obesity make it crucial that body composition research be conducted in the obese population to better understand obesity, its associated health risks, and the impact of various weight loss interventions on body composition. However, extreme obesity poses unique challenges when measuring body composition as each technology is impacted by physical size limitations, altered hydration status, variation within individuals, and alterations in composition of fat-free mass (2, 62).

It is because of the lack of data on body composition in obese individuals that this study focused on an alternative analytical technique for measuring body composition parameters. Finding an accurate method to expand body composition assessment of obese adults is critical to determine the differential impact of weight loss interventions on body composition. Additional research in body composition techniques is needed, to provide useful information about the impact of obesity, body composition, and the impact of weight loss interventions on body composition, and the risk of morbidity and mortality.

RESEARCH DESIGN AND METHODS

Experimental Design

This study used a prospective, cross-sectional design. Obese participants (n=99) enrolled in "Metabolic Consequences of Low and High Carbohydrate Diets" (a.k.a., Insight Weight Loss Study) were studied before starting a 6-month behavioral weight loss intervention. Whole body and left and right half-body DEXA scan analyses and BIA were used to measure components of body composition. Mean differences and agreement in body composition parameters (fat mass, lean mass, bone mineral content, fat-free mass, and percent body fat) between methods were compared. Linear regression was also used to explore variables that may predict differences between body composition methods.

Subjects

Participants included in this sub-analysis were men and non-pregnant or lactating women who were obese (BMI 30-50 kg/m^2) and weight stable, who weighed less than 155 kg, and were less than 193 cm tall. Each participant had to fit completely within the DEXA scanning area when positioned for a full body scan and have symmetrical bodies (no spinal abnormalities, amputations, etc). Men and women also had to have >20% body fat and >30% body fat, respectively, to be included in the analysis of fat-free mass using bioresistance as assessed by bioelectrical impedance analysis. Additional inclusion and exclusion criteria established for participation in the Insight Weight Loss Study are provided in Table 5.

Table 5. Inclusion and exclusion criteria for Insight Weight Loss Study.

INCLUSION CRITERIA

>21 years of age

BMI 27-50 kg/m^2

Normal or stable high blood pressure when taking 3 or fewer hypertension medications

Fasting glucose <126 mg/dl

Fasting total cholesterol <260 mg/dl

Fasting total triglycerides <300 mg/dl

Permission by primary care provider

Normal liver and kidney function

Able to give consent

Willing to modify diet and other health behaviors

EXCLUSION CRITERIA

Pregnant or lactating women

Major debilitating mental or physical illness

Contraindication for weight loss (e.g. malignancy or other serious condition)

Renal insufficiency (GFR<60 ml/min as assessed by Cockroft-Gault equation)

Cardiovascular disease event in past year

Cancer diagnosis or treatment in the past two years

Psychiatric hospitalization within preceding two years

Consumption of more then three alcoholic drinks a day

Type 1 or 2 diabetes

Use of hypolipidemics, anti-psychotics, hypoglycemics, antidepressants

Plans to move and/or become pregnant before study ends

Current participation in another clinical trial

Measurements

Participants arrived between 7:00 am and 8:30 am after a 12-hour overnight fast for their scheduled morning appointments at the General Clinical Research Center (GCRC) at Oregon Health & Science University (OHSU), Portland, Oregon. Written informed consent was obtained and Health Insurance Portability and Accountability Act (HIPAA) forms were signed by each participant (See Appendix A & B). Participants then changed from street clothing into a hospital gown and removed all metal-containing accessories. Each female participant provided a spot urine sample to confirm non-pregnant status (Acceava hCG Combo test kit, Thermo BioStar, Boulder, CO). Trained and licensed technicians in the GCRC's Body Energy and Composition Core (BECC) facility performed all body composition measurements. The equipment was calibrated each morning before performing any measurements.

Weight and Height Measurements

Body weight was measured twice using a digital scale (Scale-Tronix, Model 5002, Wheaton, IL) and the average weight measurement recorded to the nearest 0.01 kg. Height was measured to the nearest 0.01 cm using a wall-mounted stadiometer (Harpenden Stadiometer, Holtain Ltd, Crymych, UK). Body Mass Index (BMI) was calculated as the ratio of the weight in kilograms divided by the height in meters-squared.

Bioelectrical Impedance Analysis

Body composition was first measured by bioelectrical impedance analysis (BIA: Body Composition Analyzer, Model 310e, Biodynamics Corp., Seattle, WA). The

participant was asked to lie down on the DEXA scanning table and four electrodes were attached to removable adhesive electrode pads placed on the left wrist between the second and third finger and at the crease in the wrist, and between the first and second toe and at the crease of the ankle. After entering the participant's weight, height, age and gender into the display panel of the BIA machine, the analysis was initiated. A 50 kHz alternating current was sent between the pairs of electrodes attached at the wrist and ankle and the bioresistance of the current was recorded.

The bioresistance value was entered into a gender-specific, validated prediction equations that also takes into consideration body fat content to calculate fat-free mass (17). Whether a participant met the percent body fat criteria was confirmed by the DEXA analysis. The equations used to calculate fat-free mass from bioresistance were:

Women, >30% body fat:

Fat-free mass (kg) =

$0.00091186*[\text{height (cm)}^2] - 0.01466*[\text{bioresistance}] + 0.2999*[\text{weight (kg)}] - 0.07012*[\text{age (yr)}] + 9.37938$

Men, >20% body fat:

Fat-free mass (kg) =

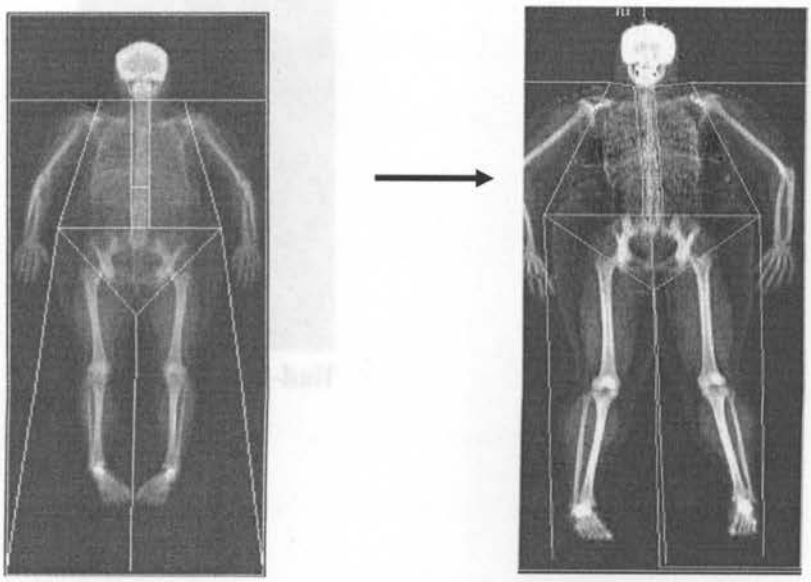
$0.0008858*[\text{height (cm)}^2] - 0.02999*[\text{bioresistance}] + 0.42688*[\text{weight (kg)}] - 0.07002*[\text{age (yr)}] + 14.52435$

Fat mass was then calculated as the difference between total body weight and fat-free mass and percent body fat was calculated as the ratio of fat mass to body weight multiplied by 100.

Dual-Energy X-ray Absorptiometry Analysis

The participant was then positioned inside the dual-energy X-ray absorptiometry (DEXA) scanning area so that the right side of their body was adjacent to the C-arm of the DEXA machine (Hologic, Inc., QDR Discovery A, Bedford, MA). Participants laid on the scanning table in a supine position with their arms at their sides and palms flat against their body (vertical to the scanning bed) (Figure 1a). Their feet were positioned with the toes touching and slightly turned in. The participant's head was positioned at the upper scan limit line and adjustments were made so that the spine was as straight as possible. Immediately before the scan was performed the position of the participant was examined to make sure that both the upper right and left arms and the torso were within the scanning area (Figure 1b). A single DEXA scan of the whole body was performed. When the scanning procedure was complete, the participant changed back into his/her street clothes and was provided a complementary continental breakfast.

Figure 1. Example of positioning for a whole body DEXA scan. Arrow identifies where portion of right arm was eliminated in DEXA scan analysis.

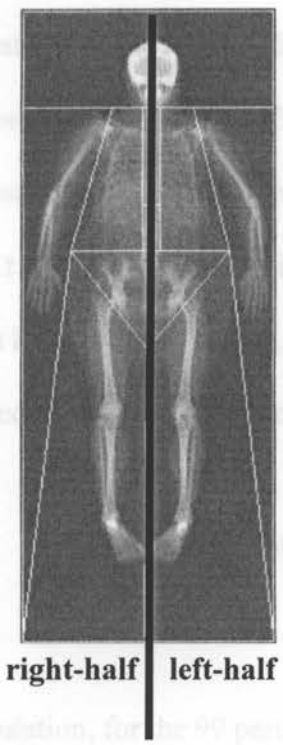


a b

DEXA Scan Analyses

DEXA scans were analyzed using the computer software program Hologic QDR for Windows XP Software Version 12.1. Each scan was analyzed twice: once to generate whole body composition data and again to generate right-half and left-half regional body composition data. The right and left half regional data was generated by positioning a sagittal line along the midline of the scanned image using the skull, spine, pelvis and legs as anatomical reference points (see Figure 2). The output for each analysis included total body mass, fat mass (lean mass plus bone mineral content), bone mineral content, bone area, bone density, lean mass, fat-free mass, and percent body fat.

Figure 2. Whole body DEXA scan analysis. Line represents differentiation of left-half and right-half of the body.



STATISTICAL ANALYSIS

Sample Size Calculations

This study did not use a power calculation to determine power with specific sample sizes since sample size was predetermined by the Insight Weight Loss Study. Additionally, the purpose of this study was to analyze equivalence and mean differences between whole body DEXA scan analyses and right half and left half-body DEXA scan analyses, and whole body DEXA scan analysis and BIA. Therefore, confidence interval widths were estimated for the 99 obese individuals that underwent DEXA and BIA measurements.

To estimate confidence interval width, preliminary data collected and analyzed from 15 subjects in a previous study was used (See Preliminary Data in Appendix C). The standard deviations of the mean differences for fat mass (SD = 0.66) and lean mass (SD = 1.15) between the whole body DEXA scan analyses and two times the left half-body DEXA assessments were used. To calculate the width of the confidence interval, the corresponding t statistic was multiplied by the standard deviation, and then multiplied by two, to account for two-tailed testing, and finally divided by the square root of the sample size (n) according to the following equations:

$$\text{width of confidence interval} = \frac{2\,(t)\,(SD)}{\sqrt{n}}$$

Based on this calculation, for the 99 participants in this study, it is estimated that lean mass will provide a confidence interval width of 0.46 kg while fat mass will provide a confidence interval width of 0.26 kg. This confidence interval width is small, however, it

does not tell us the magnitude of the differences or the level of agreement between body composition techniques.

Data Cleaning and Calculations

Data collected from BIA and DEXA scan analyses were recorded in standard spreadsheets (Excel, Microsoft Office 2000 version 9.0). Body composition parameters measured by half-body DEXA scan analyses were multiplied by two to compare to parameters measured by whole body DEXA scan analysis. Body-fat and gender-specific prediction equations were used to calculate fat-free mass from bioresistance data determined by BIA (17). Fat mass was calculated by subtracting the fat-free mass from the total body mass. The BIA and DEXA spreadsheets were merged into one and imported into SPSS (Version 13.0 for Windows, Chicago, IL) and SAS (Version 9.1 for Windows, Cary, NC) spreadsheets. For each parameter (fat mass, lean mass, bone mineral content, fat-free mass, and percent body fat), values obtained by half-body DEXA analysis and BIA were subtracted from values obtained by whole body DEXA analysis to calculate the differences between methods for each participant. Differences that stood out from the others by visual inspection were investigated further to ensure data was entered correctly. Scatterplot analysis of whole body DEXA analysis values versus both left and right half-body DEXA analysis values and BIA values for each body composition parameter were also used to identify outliers.

Data Analysis

Fat mass, fat-free mass, lean mass, bone mineral content and percent body fat were compared among techniques. Descriptive statistics including mean, standard deviation, minimum, and maximum values, and within subject correlations of body composition parameters measured by each technique were obtained. Since previous studies referred to DEXA as the best technique for measuring body composition in obese individuals (2, 18), the traditional whole body analysis was used as the reference or standard to which other methods were compared. Student paired t-tests were used to determine whether mean differences between body composition techniques were significantly different from zero. P-values less than 0.05 were considered significant. The magnitude and direction of the mean difference, as well as the upper and lower bounds of the 95% confidence interval were obtained.

Regression Analysis

Univariate regression models were constructed with age, BMI, weight, height and gender as the independent variables, which were placed into a model with each dependent variable. Ethnicity was not included since there were only five nonwhite adults in the sample studied. Differences in whole body and two times the right half-body DEXA analyses, whole body and two times the left half-body DEXA analyses, and whole body DEXA analysis and BIA for each body composition parameter were entered into the model as the dependent variables. The relationships between each independent and dependent variable and the correlations were analyzed, and models were analyzed for trends.

Multivariate linear regression models were also created. Full multivariate regression models were constructed for each dependent variable that included age, gender, weight, height and BMI as the independent variables. The backward selection method was used to determine the final models for each dependent variable. A significance level of $p = 0.2$ was used as the independent variable selection criteria, and the variable with the highest p-value was eliminated first from the model. Variables were sequentially removed until the final regression model included only significant independent variables. Standardized residuals (the difference between an observation and the expected value, adjusted for variance) were plotted against the predicted values for both the full and final regression models. These figures were used to check all assumptions for a multivariate regression model including normal distribution, equal variance, linear relationship, and that variables were measured without error.

Limits of Agreement

Since this study compared three different body composition methods all within the same individual and on the same day, the body composition parameters were expected to be highly correlated and the mean differences between techniques to be small. If the true differences between whole body and right half-body DEXA analyses, whole body and left half-body DEXA analyses and whole body DEXA analysis and BIA, are normally distributed then approximately 95% of the difference values are expected to fall within the mean plus or minus two times the standard deviation ($\mu \pm 2\sigma$). The mean difference (μ) plus or minus two times the standard deviation, designated as ($\mu - 2\sigma$) and ($\mu + 2\sigma$), were estimated using sample data (estimate of mean difference = d, estimate of

standard deviation = s). These estimates refer to the lower and upper limits of agreements, respectively (67). Since these limits are only estimates, 95% confidence intervals for both ($\mu - 2\sigma$) and ($\mu + 2\sigma$) were obtained using the method developed by Bland and Altman (67) using the following equation:

95% Confidence Interval = lower or upper limit of agreement ±

[(t statistic x standard error (SE)]

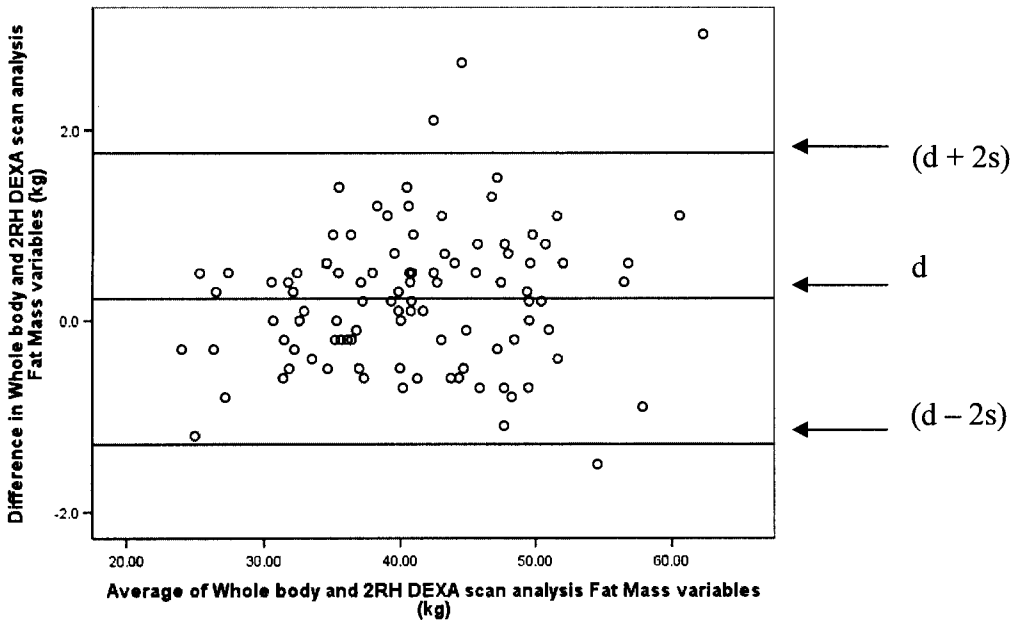
where SE = $\sqrt{[\{3(s^2)\}/n]}$

These confidence intervals provide an estimate of the accuracy of the upper and lower limits of agreement.

Bland and Altman Plots

The average of the whole body DEXA scan analysis and two times the right-half DEXA scan analysis, whole body DEXA scan analysis and two times the left-half DEXA scan analysis, and whole body DEXA analysis and BIA, for fat mass, lean mass, bone mineral content, fat-free mass, and percent body fat for each participant was calculated. These averages were plotted against the mean differences for each corresponding measurement. A y-axis reference line was plotted for the mean of the difference between the two body composition methods being compared. Two other y-axis reference lines were placed to designate the lower and upper limits of agreement ($d \pm 2s$) as shown in Figure 4.

Figure 4. Example of Bland and Altman plot.



RESULTS

Descriptive Statistics

One hundred and forty four participants were available for analysis. Participants who were excluded from analysis were sixteen participants who had BMI <30 kg/m^2, twenty seven participants who exceeded the DEXA scanning area, and two participants who exceeded the manufacturer's weight limit (weight >350 pounds). Ninety-nine participants met the inclusion criteria for the subanalysis. One participant was excluded from the DEXA and BIA analysis because she did not meet the criteria for the BIA obese-specific equation (her percent body fat by whole body DEXA analysis was <30%). Of the 98 participants who met the criteria for this subanalysis, 68 were female and 30 were male; 93 were white and 5 were nonwhite (Black/African American). Participant characteristics are presented in Table 6.

Table 6. Participant Characteristics (n = 98)

Variable	Mean ± SD	Range
Age (yr)	50.8 ± 10.6	29 - 76
Weight (kg)	103.1 ± 13	75.4 – 137.6
Height (cm)	168.6 ± 8.4	153.1 – 187.6
Body Mass Index (kg/m^2)	36.4 ± 4.2	30.2 – 48.5

The means for fat mass, lean mass, bone mineral content, fat-free mass and percent body fat for each method are presented in Table 7.

Table 7. Mean and standard deviation for each body composition parameter by whole body DEXA scan analysis, right and left half-body DEXA scan analysis, and BIA.

	Fat Mass (kg)		Fat-Free Mass (kg)		Percent Body Fat (%)	
Method	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
WB [1]	41.3 ± 8.3	23.9 - 63.8	62.5 ± 11.5	41.2 - 92.9	40.2 ± 6.6	23.5 - 49.9
2RH[2]	41.0 ± 8.1	24.2 - 60.8	63.0 ± 11.6	42.7 - 94.3	39.9 ± 6.6	23.7 - 49.7
2LH[3]	41.9 ± 8.5	23.5 - 67.5	63.0 ± 11.8	39.8 - 93.1	40.4 ± 6.6	23.4 - 49.9
BIA[4]	42.1 ± 6.5	29.1 - 51.2	59.8 ± 10.6	40.9 –85.0	42.2 ± 6.4	29.1 –51.2

	Lean Mass (kg)		Bone Mineral Content (kg)	
Method	Mean ± SD	Range	Mean ± SD	Range
WB	61.3 ± 10.9	41.2 - 89.7	2.4 ± 0.4	1.8 - 3.5
2RH	60.6 ± 11.3	40.6 - 91.0	2.4 ± 0.4	1.7 - 3.7
2LH	60.6 ± 11.5	38.0 - 89.9	2.4 ± 0.4	1.8 - 3.4

[1]WB = Whole body DEXA scan analysis
[2]2RH = Two times the right half-body DEXA scan analysis
[3]2LH = Two times the left half-body DEXA scan analysis
[4]BIA = Bioelectrical impedance analysis

Correlations and Linear Relationships

Correlations between all four body composition methods for fat mass, fat-free mass and percent body fat are greater than 0.9 and were significant at the 0.01 significance level (Table 8). This level of correlation is to be expected since each body composition measurement was taken within the same individual on the same day. The linear regression models for the body composition scatterplots are presented in Table 9. The plots of the whole body DEXA versus either right half-body DEXA, left half-body DEXA or BIA for each body composition parameter illustrate this relationship (Figures 5-8).

Table 8. Correlations[1] for each body composition parameter measured by whole body DEXA scan analysis, half-body DEXA scan analyses, and BIA.

		FAT MASS		
	WB[2]	*2RH*[3]	*2LH*[4]	*BIA*[5]
WB	1.000	0.996	0.995	0.944
2RH	0.996	1.000	0.983	0.933
2LH	0.995	0.983	1.000	0.945
BIA	0.944	0.933	0.945	1.000
		LEAN MASS		
	WB	*2RH*	*2LH*	*BIA*
WB	1.000	0.996	0.994	- - -
2RH	0.996	1.000	0.982	- - -
2LH	0.994	0.982	1.000	- - -
BIA	- - -	- - -	- - -	- - -
		BONE MINERAL CONTENT		
	WB	*2RH*	*2LH*	*BIA*
WB	1.000	0.989	0.985	- - -
2RH	0.989	1.000	0.953	- - -
2LH	0.985	0.953	1.000	- - -
BIA	- - -	- - -	- - -	- - -
		FAT-FREE MASS		
	WB	*2RH*	*2LH*	*BIA*
WB	1.000	0.996	0.994	0.968
2RH	0.996	1.000	0.982	0.963
2LH	0.994	0.982	1.000	0.964
BIA	0.968	0.963	0.964	1.000

[1]All correlations are significant at the 0.01 level.
[2]WB = Whole body DEXA scan analysis
[3]2RH = Two times right half-body DEXA scan analysis
[4]2LH = Two times left half-body DEXA scan analysis
[5]BIA = Bioelectrical impedance analysis

Table 8 continued; Correlations for each body composition parameter measured by whole body DEXA scan analysis, half-body DEXA scan analyses, and BIA.

PERCENT BODY FAT				
	WB	*2RH*	*2LH*	*BIA*
WB	1.000	0.998	0.998	0.921
2RH	0.998	1.000	0.992	0.915
2LH	0.998	0.992	1.000	0.923
BIA	0.921	0.915	0.923	1.000

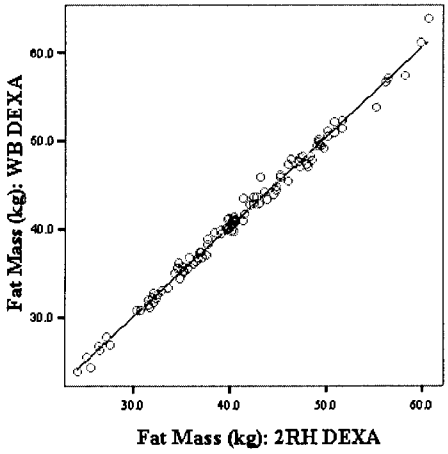
[1]All correlations are significant at the 0.01 level.
[2]WB = Whole body DEXA scan analysis
[3]2RH = Two times right half-body DEXA scan analysis
[4]2LH = Two times left half-body DEXA scan analysis
[5]BIA = Bioelectrical impedance analysis

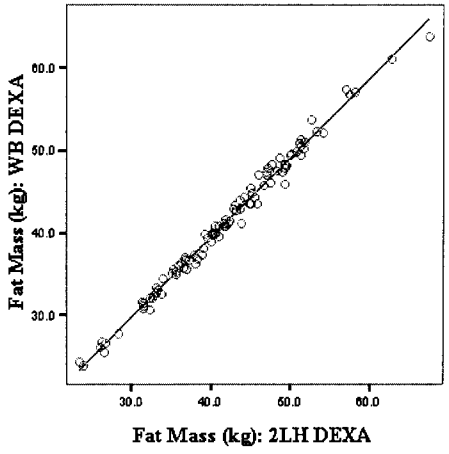
Table 9. Linear regression of each body composition parameter of half-body DEXA scan analyses and BIA compared to whole body DEXA scan analysis.

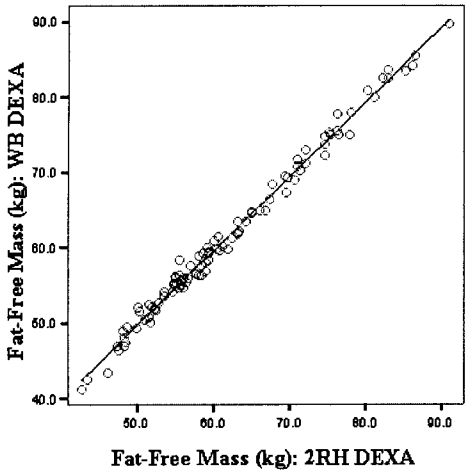
Body Composition Parameter	**Method Compared to Whole body DEXA**	**Slope estimate**	**R^2**
Fat Mass (kg)	Right half-body DEXA	1.01	0.99
	Left half-body DEXA	0.97	0.99
	BIA[1]	0.91	0.89
Lean Mass (kg)	Right half-body DEXA	0.99	0.99
	Left half-body DEXA	0.97	0.99
Bone Mineral Content (kg)	Right half-body DEXA	0.93	0.98
	Left half-body DEXA	1.00	0.97
Fat-Free Mass (kg)	Right half-body DEXA	0.99	0.99
	Left half-body DEXA	0.97	0.99
	BIA	1.00	0.94
Percent Body Fat (%)	Right half-body DEXA	1.00	1.00
	Left half-body DEXA	1.00	1.00
	BIA	0.95	0.85

[1]BIA = Bioelectrical impedance analysis

Figure 5. Whole body versus Half-body DEXA scan analysis: Fat and Fat-free Mass.







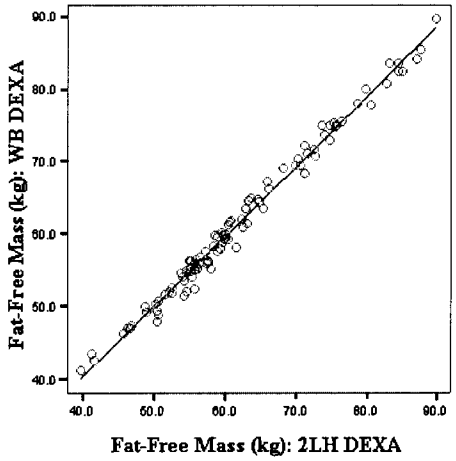
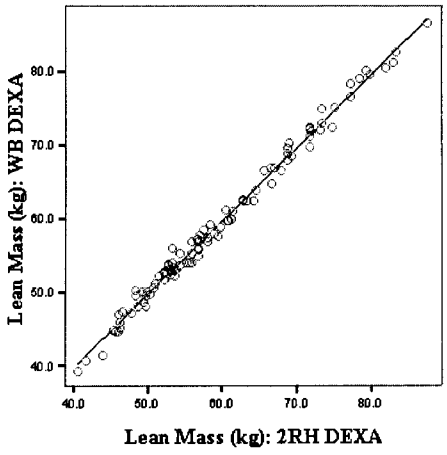
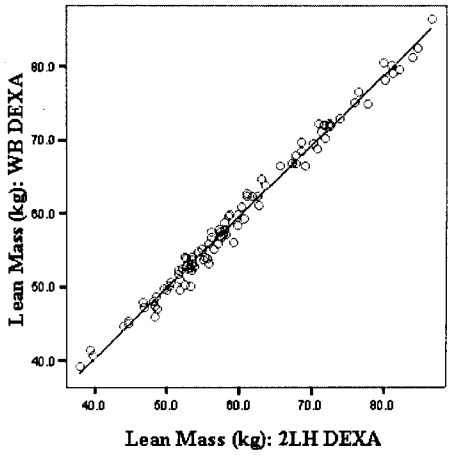
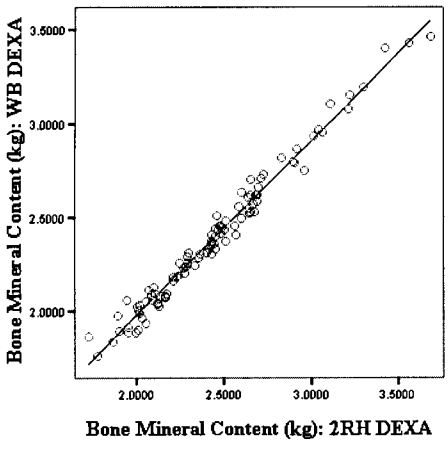


Figure 6. Whole body versus Half-body DEXA scan analysis: Lean Mass and Bone Mineral Content.







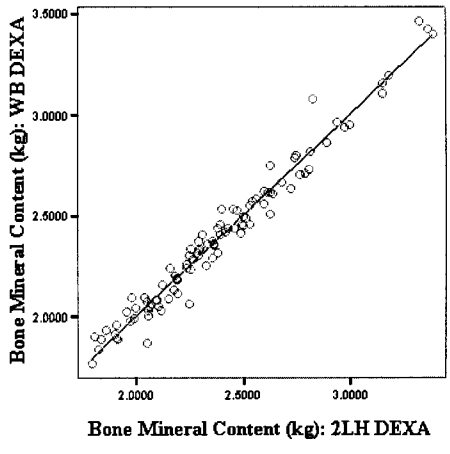


Figure 7. Whole body versus Half-body DEXA scan analysis: Percent Body Fat.

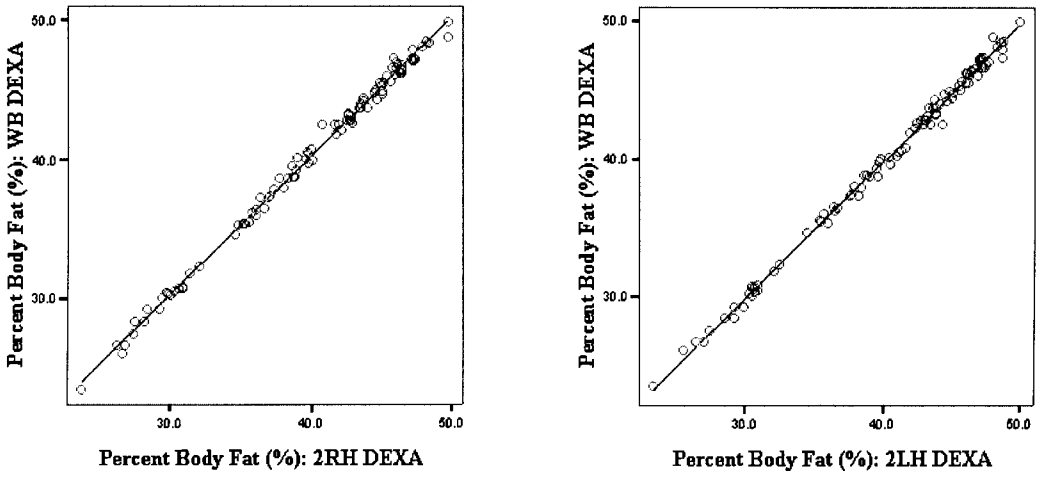
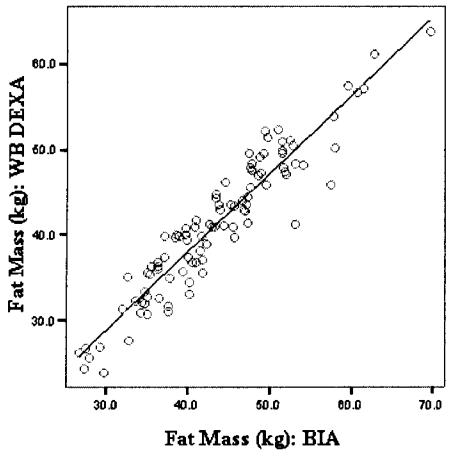
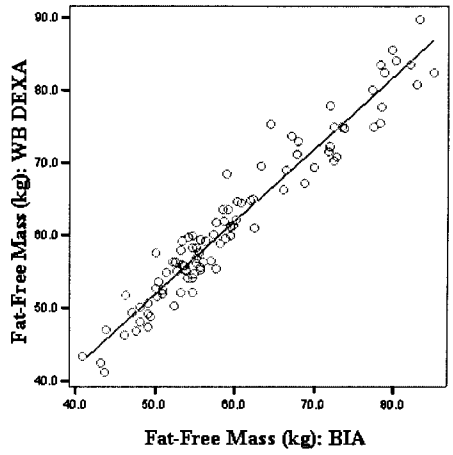
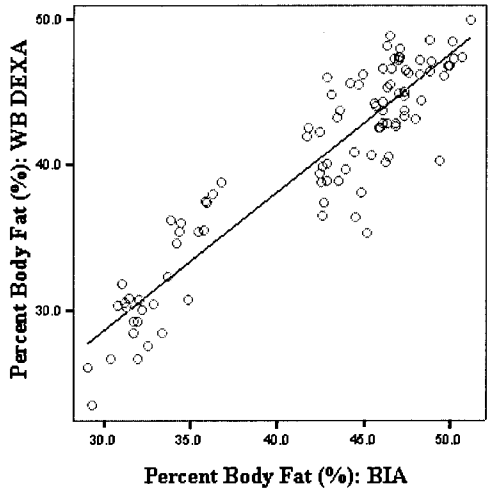


Figure 8. Whole body DEXA scan analysis versus BIA: Fat and Fat-Free Mass, and Percent Body Fat.







Univariate Linear Regression

When each dependent variable was plotted against each independent variable, no relationships were observed (Figures 9-12 in Appendix D). More formal analyses using univariate linear regression models, were explored with each independent variable versus each dependent variable. The correlation coefficient and slope estimates are presented from each of these univariate regression models in Table 10 and no trends were identified for any of the models.

Table 10. Univariate regression models for body composition parameters.

FAT MASS						
	WB[1] – 2RH[2]		WB – 2LH[3]		WB – BIA[4]	
	Slope estimate[6] (p)	R^2	Slope estimate (p)	R^2	Slope estimate (p)	R^2
Weight (kg)	0.015	0.07	-0.021	0.10	-0.039	0.03
	(0.01)		(0.00)		(0.08)	
Height (cm)	0.004	0.00	-0.011	0.01	-0.036	0.01
	(0.67)		(0.31)		(0.29)	
BMI[5] (kg/m^2)	*0.045*	0.06	*-0.051*	0.06	-0.077	0.01
	(0.01)		*(0.01)*		(0.27)	
Gender	-0.199	---	0.104	---	1.122	---
	(0.24)		(0.59)		(0.07)	
Age (yr)	0.003	0.00	-0.001	0.00	-0.017	0.00
	(0.73)		(0.90)		(0.52)	

[1]WB = Whole body DEXA scan analysis
[2]2RH = Right half-body DEXA scan analysis
[3]2LH = Left half-body DEXA scan analysis
[4]BIA = Bioelectrical impedance analysis
[5]BMI = Body mass index
[6]For continuous variables (weight, height, BMI and age), the parameter estimate is the estimated amount that the mean difference in the body composition measurement increases per unit increase in the continuous variable. For gender, a categorical variable, the parameter estimate is an estimate of the mean difference in body composition methods for males minus the mean differences for females.

Table 10 continued: Univariate regression models for body composition parameters.

LEAN MASS

	WB[1] – 2RH[2]		WB – 2LH[3]		WB – BIA[4]	
	Slope estimate[6] (p)	R^2	Slope estimate (p)	R^2	Slope estimate (p)	R^2
Weight (kg)	0.008	0.01	-0.022	0.05	---	---
	(0.29)		(0.02)			
Height (cm)	-0.003	0.00	-0.026	0.03	---	---
	(0.78)		(0.07)			
BMI (kg/m^2)	0.044	0.03	-0.035	0.01	---	---
	(0.08)		(0.24)			
Gender	-0.279	---	-0.190	---	---	---
	(0.21)		(0.48)			
Age (yr)	-0.002	0.00	0.006	0.00	---	---
	(0.83)		(0.61)			

[1]WB = Whole body DEXA scan analysis
[2]2RH = Right half-body DEXA scan analysis
[3]2LH = Left half-body DEXA scan analysis
[4]BIA = Bioelectrical impedance analysis
[5]BMI = Body mass index
[6]For continuous variables (weight, height, BMI and age), the parameter estimate is the estimated amount that the mean difference in the body composition measurement increases per unit increase in the continuous variable. For gender, a categorical variable, the parameter estimate is an estimate of the mean difference in body composition methods for males minus the mean differences for females.

Table 10 continued; Univariate regression models for body composition parameters.

BONE MINERAL CONTENT						
	WB[1] – 2RH[2]		WB – 2LH[3]		WB – BIA[4]	
	Slope estimate[6] (p)	R^2	Slope estimate (p)	R^2	Slope estimate (p)	R^2
Weight (kg)	-0.001	0.02	0.0002	0.00	---	---
	(0.13)		(0.69)			
Height (cm)	-0.002	0.05	0.001	0.02	---	---
	(0.03)		(0.21)			
BMI[5] (kg/m^2)	0.001	0.00	-0.001	0.00	---	---
	(0.74)		(0.52)			
Gender	-0.027	---	0.016	---	---	---
	(0.04)		(0.27)			
Age (yr)	-0.001	0.01	0.001	0.02	---	---
	(0.35)		(0.16)			

[1]WB = Whole body DEXA scan analysis
[2]2RH = Two times the right half-body DEXA scan analysis
[3]2LH = Two times the left half-body DEXA scan analysis
[4]BIA = Bioelectrical impedance analysis
[5]BMI = Body mass index
[6]For continuous variables (weight, height, BMI and age), the parameter estimate is the estimated amount that the mean difference in the body composition measurement increases per unit increase in the continuous variable. For gender, a categorical variable, the parameter estimate is an estimate of the mean difference in body composition methods for males minus the mean differences for females.

Table 10 continued; Univariate regression models for body composition parameters.

FAT FREE MASS

	WB[1] – 2RH[2]		WB – 2LH[3]		WB – BIA[4]	
	Slope estimate[6] (p)	R^2	Slope estimate (p)	R^2	Slope estimate (p)	R^2
Weight (kg)	0.008	0.01	-0.021	0.05	0.025	0.01
	(0.34)		(0.03)		(0.25)	
Height (cm)	-0.006	0.00	-0.026	0.03	0.045	0.02
	(0.65)		(0.08)		(0.17)	
BMI (kg/m^2)	0.046	0.03	-0.034	0.01	0.017	0.00
	(0.07)		(0.27)		(0.80)	
Gender	-0.323	---	-0.179	---	-0.817	---
	(0.16)		(0.52)		(0.18)	
Age (yr)	-0.003	0.00	0.008	0.00	0.012	0.00
	(0.73)		(0.50)		(0.64)	

[1]WB = Whole body DEXA scan analysis
[2]2RH = Two times the right half-body DEXA scan analysis
[3]2LH = Two times the left half-body DEXA scan analysis
[4]BIA = Bioelectrical impedance analysis
[5]BMI = Body mass index
[6]For continuous variables (weight, height, BMI and age), the parameter estimate is the estimated amount that the mean difference in the body composition measurement increases per unit increase in the continuous variable. For gender, a categorical variable, the parameter estimate is an estimate of the mean difference in body composition methods for males minus the mean differences for females.

Table 10 continued; Univariate regression models for body composition parameters.

PERCENT BODY FAT						
	WB[1] – 2RH[2]		WB – 2LH[3]		WB – BIA[4]	
	Slope estimate[6] (p)	R^2	Slope estimate (p)	R^2	Slope estimate (p)	R^2
Weight (kg)	0.001	0.00	-0.001	0.00	-0.013	0.00
	(0.74)		(0.86)		(0.53)	
Height (cm)	-0.0004	0.00	-0.001	0.00	-0.023	0.01
	(0.94)		(0.83)		(0.48)	
BMI[5] (kg/m^2)	0.001	0.00	0.004	0.00	-0.016	0.00
	(0.96)		(0.67)		(0.80)	
Gender	-0.083	---	0.034	---	0.952	---
	(0.39)		(0.72)		(0.10)	
Age (yr)	0.003	0.01	-0.004	0.01	-0.017	0.00
	(0.48)		(0.32)		(0.50)	

[1]WB = Whole body DEXA scan analysis
[2]2RH = Two times the right half-body DEXA scan analysis
[3]2LH = Two times the left half-body DEXA scan analysis
[4]BIA = Bioelectrical impedance analysis
[5]BMI = Body mass index
[6]For continuous variables (weight, height, BMI and age), the parameter estimate is the estimated amount that the mean difference in the body composition measurement increases per unit increase in the continuous variable. For gender, a categorical variable, the parameter estimate is an estimate of the mean difference in body composition methods for males minus the mean differences for females.

Full and Final Linear Regression Models

The full regression models are displayed in Table 11. None of the models were significant with all dependent variables in the model. After eliminating non-significant variables, there were no visible trends in the final linear regression models. The final models are presented in Table 12 and included different variables with varying significance, and there was no one variable that proved to be significant for all of the models.

Table 11. Full linear regression models.

	Slope estimates[5] (p)				
WB[1] – 2RH[2]	**BMI[4]**	**Weight**	**Height**	**Gender**	**Age**
Fat Mass	0.008	0.016	0.006	-0.399	0.005
	(0.92)	(0.57)	(0.87)	(0.06)	(0.53)
Lean Mass	0.156	-0.042	0.067	-0.362	0.0003
	(0.14)	(0.27)	(0.17)	(0.22)	(0.97)
Bone Mineral Content	0.0001	-0.0003	-0.001	-0.013	-0.0004
	(0.99)	(0.90)	(0.75)	(0.47)	(0.45)
Fat-Free Mass	0.151	-0.399	0.063	-0.386	-0.001
	(0.16)	(0.30)	(0.20)	(0.20)	(0.94)
Percent Body Fat	-0.072	0.027	-0.028	-0.152	0.003
	(0.11)	(0.10)	(0.18)	(0.23)	(0.43)
WB – 2LH[3]					
Fat Mass	0.022	-0.031	0.006	0.359	-0.003
	(0.79)	(0.31)	(0.88)	(0.14)	(0.76)
Lean Mass	-0.132	0.028	-0.074	0.129	0.006
	(0.29)	(0.53)	(0.20)	(0.71)	(0.64)
Bone Mineral Content	0.001	-0.001	0.001	0.004	0.001
	(0.88)	(0.83)	(0.66)	(0.82)	(0.19)
Fat-Free Mass	-0.135	0.030	-0.077	0.139	0.008
	(0.29)	(0.51)	(0.19)	(0.70)	(0.53)
Percent Body Fat	0.078	-0.028	0.029	0.104	-0.004
	(0.07)	(0.08)	(0.14)	(0.39)	(0.32)

[1]WB = Whole body DEXA scan analysis
[2]2RH = Two times the right half-body DEXA scan analysis
[3]2LH = Two times the left half-body DEXA scan analysis
[4]BMI = Body mass index
[5]For continuous variables (weight, height, BMI and age), the slope estimate is the estimated amount that the mean difference in the body composition measurement increases per unit increase in the continuous variable. For gender, a categorical variable, the slope estimate is an estimate of the mean difference in body composition methods for males minus the mean difference for females.

Table 11 continued; Full linear regression models.

	Slope estimates[4] (p)				
WB[1] – BIA[2]	**BMI[3]**	**Weight**	**Height**	**Gender**	**Age**
Fat Mass	-0.168	0.026	-0.173	2.638	-0.029
	(0.55)	(0.79)	(0.18)	(0.001)	(0.27)
Fat-Free Mass	0.205	-0.062	0.206	-2.304	0.022
	(0.46)	(0.53)	(0.11)	(0.004)	(0.39)
Percent Body Fat	-0.195	0.064	-0.176	2.108	-0.026
	(0.46)	(0.50)	(0.15)	(0.005)	(0.29)

[1]WB = Whole body DEXA scan analysis
[2]BIA = Bioelectrical impedance analysis
[3]BMI = Body mass index
[4]For continuous variables (weight, height, BMI and age), the parameter estimate is the estimated amount that the mean difference in the body composition measurement increases per unit increase in the continuous variable. For gender, a categorical variable the parameter estimate is an estimate of the mean difference in body composition methods for males minus the mean difference for females.

Table 12. Final linear regression models.

Dependent Variable	Intercept	Independent Variables	Slope estimate[6]	p
FAT MASS				
WB[1] – 2RH[2]	-1.623	weight	0.019	<0.01
		gender	-0.365	0.03
WB – 2LH[3]	1.763	weight	-0.024	<0.01
		gender	0.315	0.09
WB – BIA[4]	18.183	height	-0.126	<0.01
		gender	2.599	<0.01
LEAN MASS				
WB – 2RH	2.006	BMI	0.044	0.08
WB – 2LH[3]	7.462	BMI	-0.057	0.07
		height	-0.035	0.02
(2^{nd} model)	1.811	weight	-0.022	0.02
BONE MINERAL CONTENT				
WB – 2RH	0.222	height	-0.002	0.03
WB – 2LH	---	---	---	---

[1]WB = Whole body DEXA scan analysis
[2]2RH = Two times the right half-body DEXA scan analysis
[3]2LH = Two times the left half-body DEXA scan analysis
[4]BIA = Bioelectrical impedance analysis
[5]BMI = Body mass index
[6]For continuous variables (weight, height, BMI and age), the parameter estimate is the estimated amount that the mean difference in the body composition measurement increases per unit increase in the continuous variable. For gender, a categorical variable the parameter estimate is an estimate of the mean difference in body composition methods for males minus the mean difference for females.

Table 12 continued; Final linear regression models.

Dependent Variable	Intercept	Independent Variables	Slope estimate[6]	p
FAT-FREE MASS				
WB[1] – 2RH[2]	-2.132	BMI[5]	0.046	0.07
WB – 2LH[3]	7.362	BMI	-0.055	0.08
		height	-0.034	0.03
WB – BIA[4]	-18.290	height	0.124	<0.01
		gender	-2.262	<0.01
PERCENT BODY FAT				
WB – 2RH	---	---	---	---
WB – 2LH	-5.845	BMI	0.079	0.07
		weight	-0.028	0.08
		height	0.034	0.09
WB - BIA	13.033	height	-0.093	0.02
		Gender	2.039	0.01

[1]WB = Whole body DEXA scan analysis
[2]2RH = Two times the right half-body DEXA scan analysis
[3]2LH = Two times the left half-body DEXA scan analysis
[4]BIA = Bioelectrical impedance analysis
[5]BMI = Body mass index
[6]For continuous variables (weight, height, BMI and age), the parameter estimate is the estimated amount that the mean difference in the body composition measurement increases per unit increase in the continuous variable. For gender, a categorical variable the parameter estimate is an estimate of the mean difference in body composition methods for males minus the mean difference for females.

Whole Body and Half-Body DEXA Comparisons

Paired t-test results for whole body and half-body DEXA comparison are presented in Table 13. Fat mass measured by two times the right half-body DEXA measurement was 0.23 kg lower than the whole body DEXA measurement, with 95% confidence that the mean difference falls between 0.08 and 0.39 kg. In contrast, two times the left half-body DEXA measurement for fat mass was 0.65 kg higher than the whole body DEXA measurement, with a 95% confidence interval of –0.82 and –0.47 kg. Lean mass measured by two times the right and two times the left half-body DEXA was 0.42 kg and 0.45 kg higher, respectively, than the whole body DEXA measurement. Bone mineral content was 0.05 kg higher by the two times the right half-body DEXA analysis, where two times the left half-body DEXA analysis was 0.01 kg lower than the whole body DEXA method. All mean differences were statistically significant ($p<0.05$) except for the mean difference of bone mineral content by the whole body DEXA and two times the left half-body DEXA methods.

Whole Body DEXA and BIA Comparisons

Paired t-test results for whole body DEXA and BIA comparison are presented in Table 14. Fat-free mass was 1.85 kg lower when measured by BIA compared to whole body DEXA, whereas fat mass was 2.31 kg higher. Percent body fat was 2.03% higher by BIA compared to whole body DEXA. All mean differences were significantly different ($p<0.05$).

Table 13. Comparison of body composition parameters measured by whole body and half body DEXA scan analyses.

Body Composition Parameter	Comparison	Mean Difference	SD	95% CI for mean difference		p
				Lower	Upper	
Fat Mass (kg)	WB[2] - 2RH[3]	0.23	0.08	0.08	0.39	<0.01
	WB - 2LH[4]	-0.65	0.09	-0.82	-0.47	<0.01
Lean Mass (kg)	WB - 2RH	-0.42	1.01	-0.62	-0.21	<0.01
	WB - 2LH	-0.45	1.21	-0.70	-0.21	<0.01
BMC[1] (kg)	WB – 2RH	-0.05	0.06	-0.06	-0.04	<0.01
	WB - 2LH	0.01	0.06	-0.01	0.02	0.29
Percent Body Fat (%)	WB - 2RH	0.30	0.43	0.22	0.39	<0.01
	WB - 2LH	-0.20	0.42	-0.29	-0.12	<0.01

[1]BMC = Bone Mineral Content
[2]WB = Whole body DEXA
[3]2RH = 2 x right half DEXA
[4]2LH = 2 x left half DEXA

Table 14. Comparison of body composition parameters measured by whole body DEXA analysis and BIA.

Body Composition Parameter	Comparison	Mean Difference	SD	95% CI for mean difference		p
				Lower	Upper	
Fat Mass (kg)	WB[1] – BIA[2]	-2.31	2.83	-2.88	-1.75	0.00
Fat-Free Mass (kg)	WB – BIA	1.85	2.76	1.29	2.40	0.00
Percent Body Fat (%)	WB – BIA	-2.03	2.61	-2.55	-1.51	0.00

[1]WB = Whole body DEXA scan analysis

[2]BIA = Bioelectrical impedance analysis

Limits of Agreement

Using the Bland Altman method (67), lower and upper limits of agreement and confidence intervals for each limit of agreement were calculated and are presented in Tables 15 and 16. The lower and upper interval widths are considerably wider for the difference between whole body DEXA analysis and BIA measurements, than for the difference between whole body and either right or left half-body DEXA analyses. Approximately 95% of the population differences for whole body and right half-body DEXA for fat mass will be between -1.29 kg and 1.76 kg (width of 3.05 kg). Both upper and lower limit values are very small and represent a small percentage of the total body mass for this population (mean weight = 103 ± 13 kg).

The confidence intervals for the lower and upper limits prove that the limits of agreement are precise. The lower limit of agreement for whole body DEXA and right half-body DEXA mean difference for fat mass (-1.26 kg) has a 95% confidence interval of –1.55 kg and –1.03 kg. Therefore, the calculated limits of agreement are good estimates of the lower and upper bounds for 95% of the population differences.

Table 15. Upper and lower limits of agreement (Bland and Altman Analysis).

	Mean Difference	SD	Limits of Agreement		Interval Width
			Lower	Upper	
FAT MASS (kg)					
WB[1] – 2RH[2]	0.23	0.76	-1.29	1.76	3.05
WB – 2LH[3]	-0.65	0.86	-2.36	1.07	3.43
WB – BIA[4]	-2.31	2.83	-7.97	3.34	11.31
LEAN MASS (kg)					
WB – 2RH	-0.42	1.01	-2.44	1.61	4.05
WB – 2LH	-0.45	1.21	-2.88	1.98	4.86
BONE MINERAL CONTENT (kg)					
WB – 2RH	-0.0499	0.0608	-0.1715	0.0716	0.2431
WB – 2LH	0.0069	0.0646	-0.1223	0.3161	0.4384
FAT-FREE MASS (kg)					
WB – 2RH	-0.47	1.03	-2.54	1.60	4.14
WB – 2LH	-0.44	1.24	-2.92	2.05	4.97
WB – BIA	1.85	2.76	-3.67	7.37	11.04
PERCENT BODY FAT (kg)					
WB – 2RH	0.30	0.43	-0.56	1.16	1.72
WB – 2LH	-0.20	0.42	-1.03	0.63	1.66
WB – BIA	1.85	2.76	-3.67	7.37	11.04

[1]WB = Whole body DEXA
[2]2RH = 2 x right half DEXA
[3]2LH = 2 x left half DEXA
[4]BIA = Bioelectrical impedance analysis

Table 16. Confidence intervals for the lower and upper limits of agreement (Bland and Altman Analysis).

		95% CI for Lower Limit		95% CI for Upper Limit	
	SE	**Lower**	**Upper**	**Lower**	**Upper**
FAT MASS					
WB[1] – 2RH[2]	0.13	-1.55	-1.03	1.49	2.02
WB – 2LH[3]	0.15	-2.66	-2.07	0.78	1.37
WB – BIA[4]	0.49	-8.95	-6.99	2.36	4.32
LEAN MASS					
WB – 2RH	0.18	-2.79	-2.09	1.26	1.96
WB – 2LH	0.21	-3.30	-2.46	1.56	2.40
BONE MINERAL CONTENT					
WB – 2RH	0.0106	-0.1925	-0.1504	0.0505	0.0926
WB – 2LH	0.0113	-0.1447	-0.0999	0.1137	0.1585
FAT-FREE MASS					
WB – 2RH	0.18	-2.90	-2.18	1.24	1.96
WB – 2LH	0.22	-3.36	-2.49	1.61	2.48
WB – BIA	0.48	-4.63	-2.72	6.41	8.32
PERCENT BODY FAT					
WB – 2RH	0.08	-0.71	-0.41	1.02	1.31
WB – 2LH	0.07	-1.18	-0.89	0.48	0.77
WB – BIA	0.46	-8.14	-6.34	2.28	4.08

[1]WB = Whole body DEXA
[2]2RH = 2 x right half DEXA
[3]2LH = 2 x left half DEXA
[4]BIA = Bioelectrical impedance analysis

Bland and Altman Plots

Plots of the whole body and half-body DEXA measurements, and the whole body DEXA and BIA measurements, and the averages and the corresponding differences for each paired body composition method (i.e. whole body DEXA and right-half DEXA analyses) were constructed to display the lower and upper limits of agreement and are described in Figures 10-22. All individual data points, except for about 4-5 points which in this data represents 4-5% of all values, fell between the upper and lower limits of agreement and showed no patterns or trends in the Bland-Altman plots. With a normal distribution, 95% of the values are expected to fall within the upper and lower limits of agreement (± 2 standard deviations), and 5% should fall outside of these limits.

Figure 10. Lower and upper limits of agreement (mean difference ± 2SD) for whole body and right half-body DEXA analyses for fat mass.

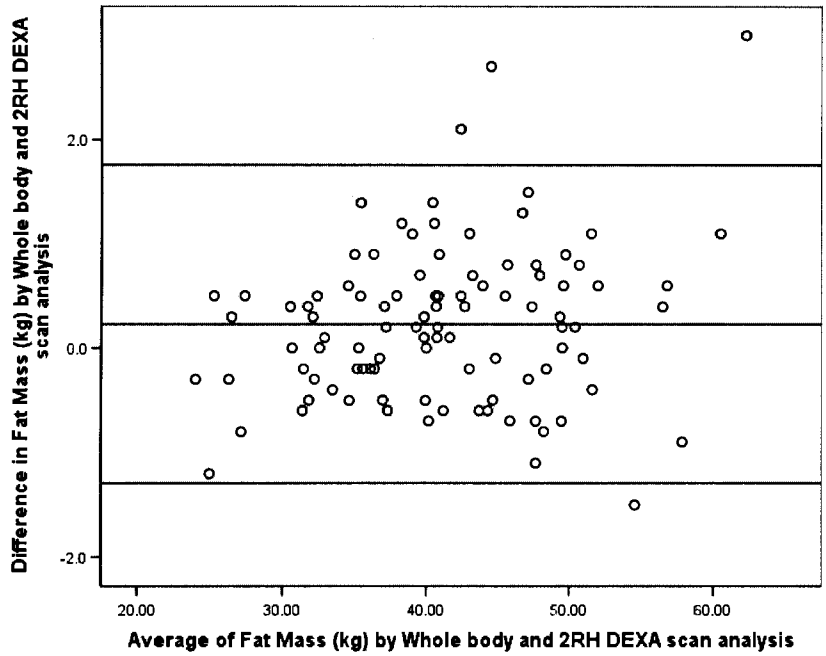


Figure 11. Lower and upper limits of agreement (mean difference ± 2SD) for whole body and left half-body DEXA analyses for fat mass.

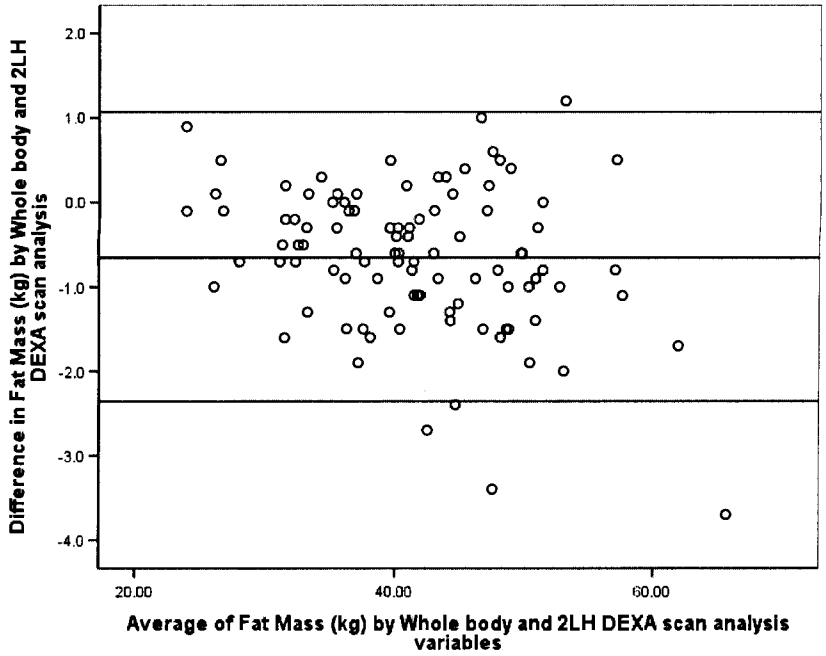


Figure 12. Lower and upper limits of agreement (mean difference ± 2SD) for whole body DEXA analysis and BIA for fat mass.

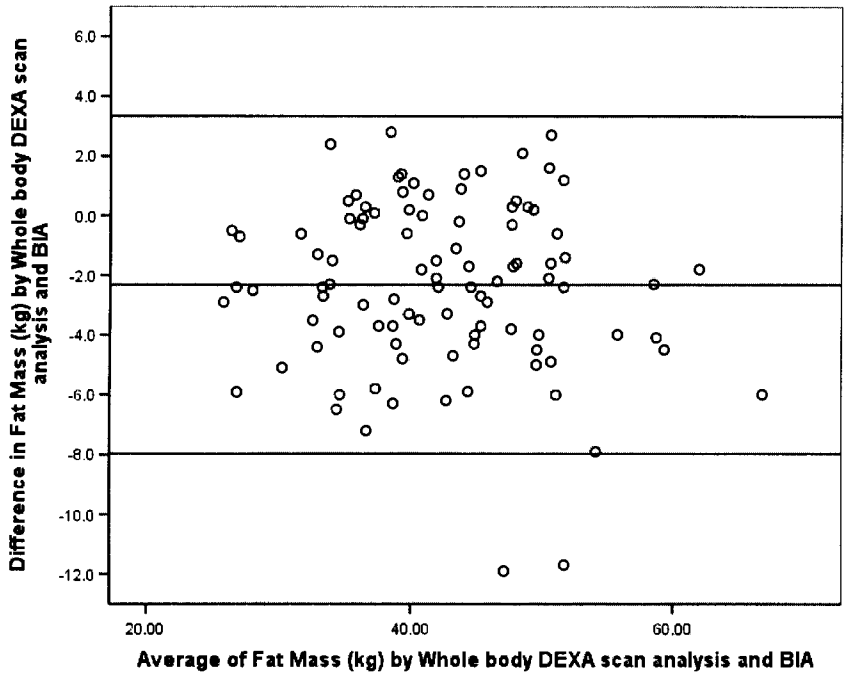


Figure 13. Lower and upper limits of agreement (mean difference ± 2SD) for whole body and right half-body DEXA analyses for fat-free mass.

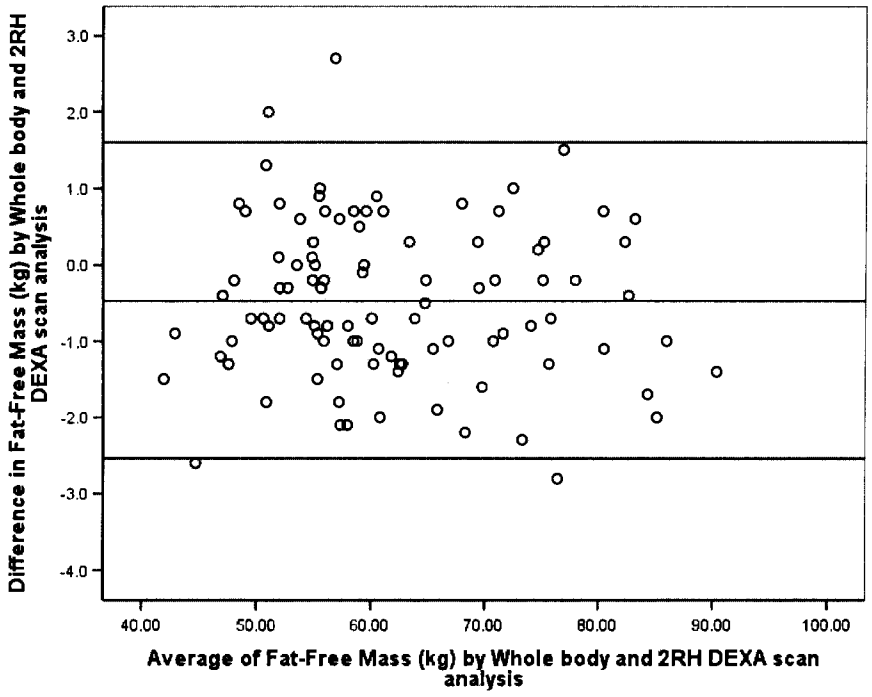


Figure 14. Lower and upper limits of agreement (mean difference ± 2SD) for whole body and left half-body DEXA analyses for fat-free mass.

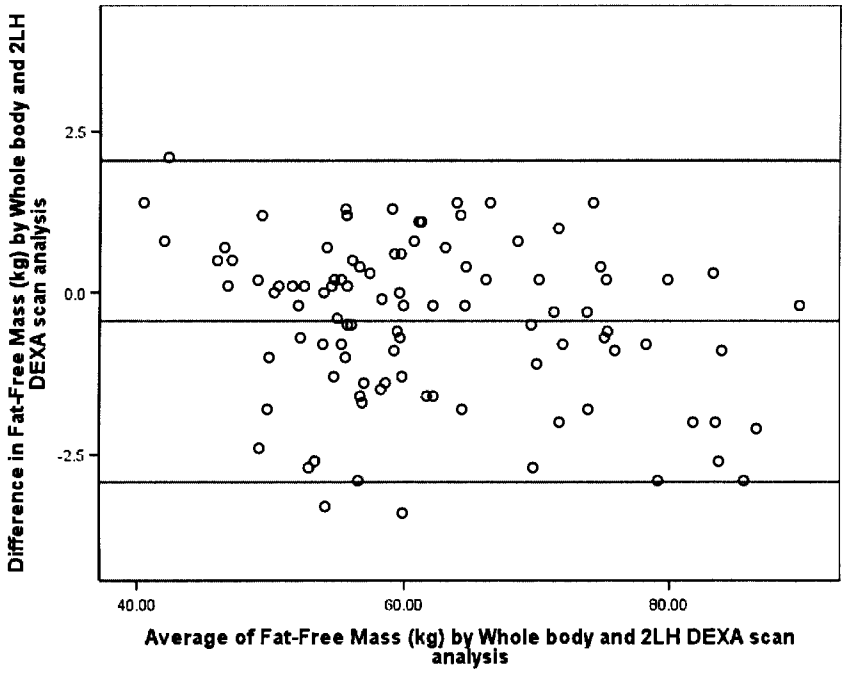


Figure 15. Lower and upper limits of agreement (mean difference ± 2SD) for whole body DEXA analysis and BIA for fat-free mass.

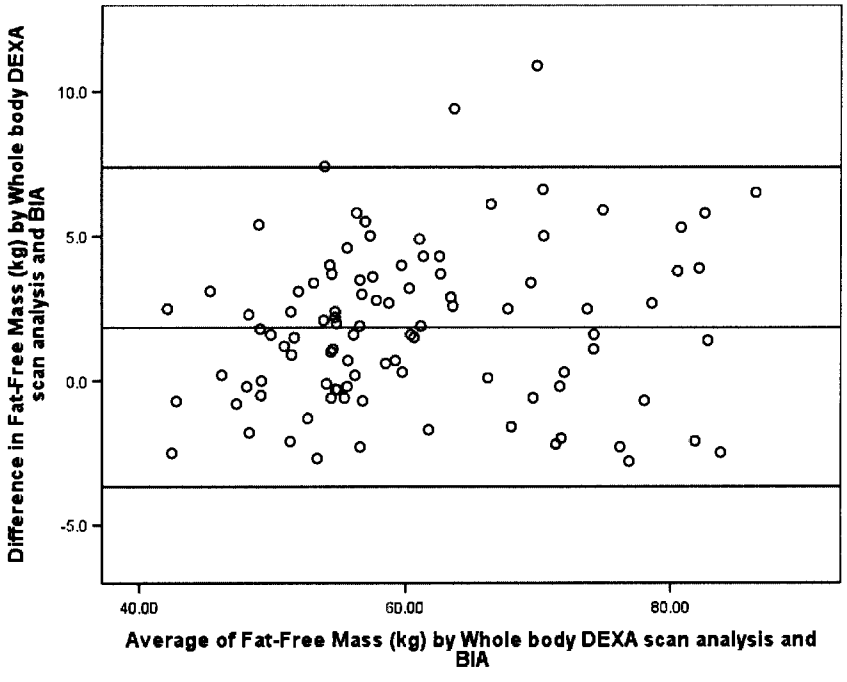


Figure 16. Lower and upper limits of agreement (mean difference ± 2SD) for whole body and right half-body DEXA analyses for percent body fat.

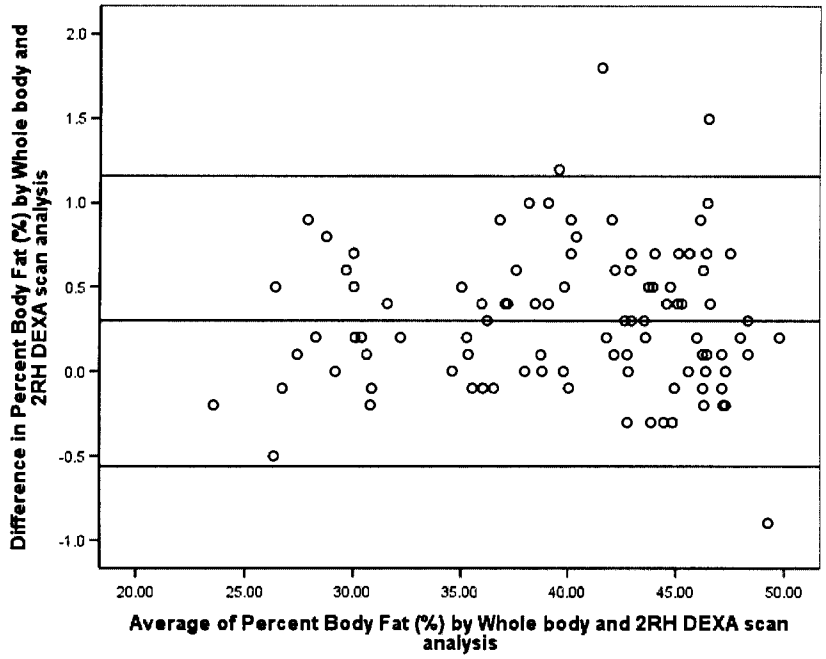


Figure 17. Lower and upper limits of agreement (mean difference ± 2SD) for whole body and left half-body DEXA analyses for percent body fat.

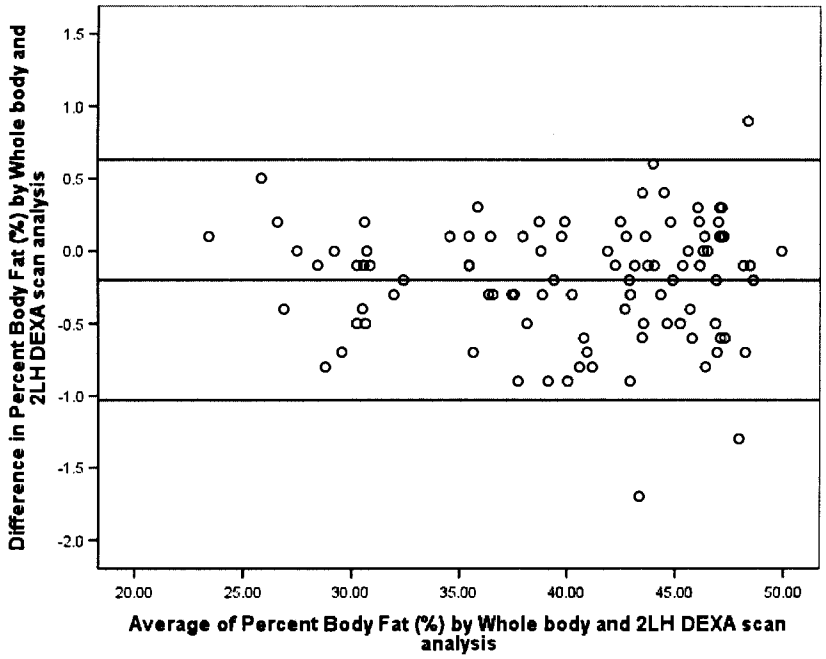


Figure 18. Lower and upper limits of agreement (mean difference ± 2SD) for whole body DEXA analysis and BIA for percent body fat.

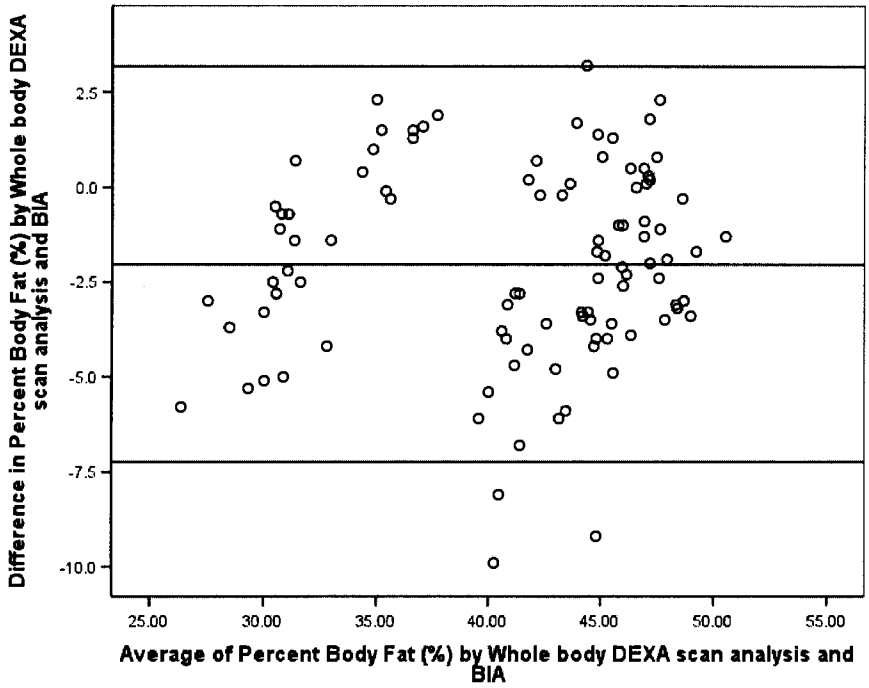


Figure 19. Lower and upper limits of agreement (mean difference ± 2SD) for whole body and right half-body DEXA analyses for lean mass.

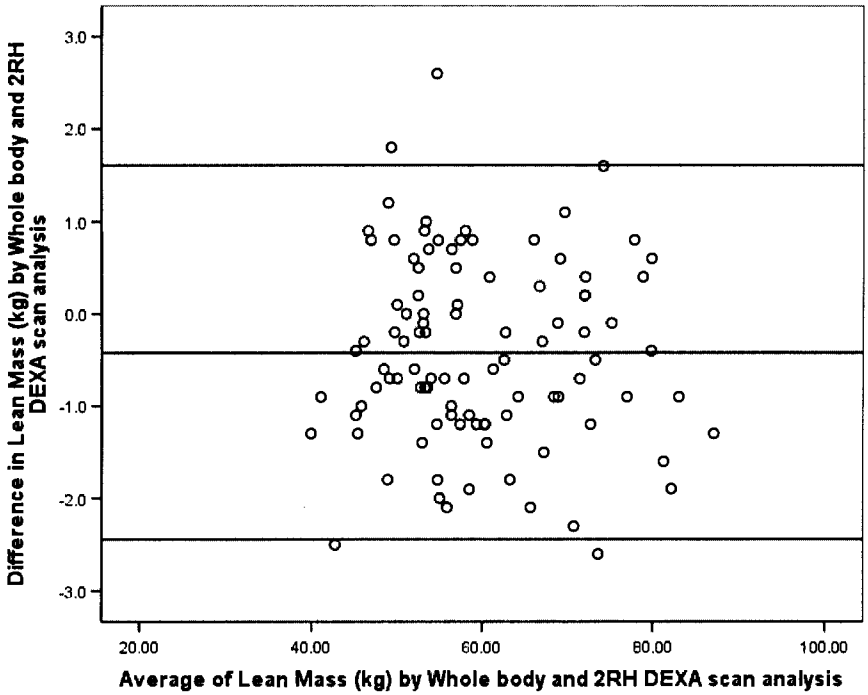


Figure 20. Lower and upper limits of agreement (mean difference ± 2SD) for whole body and left half-body DEXA analyses for lean mass.

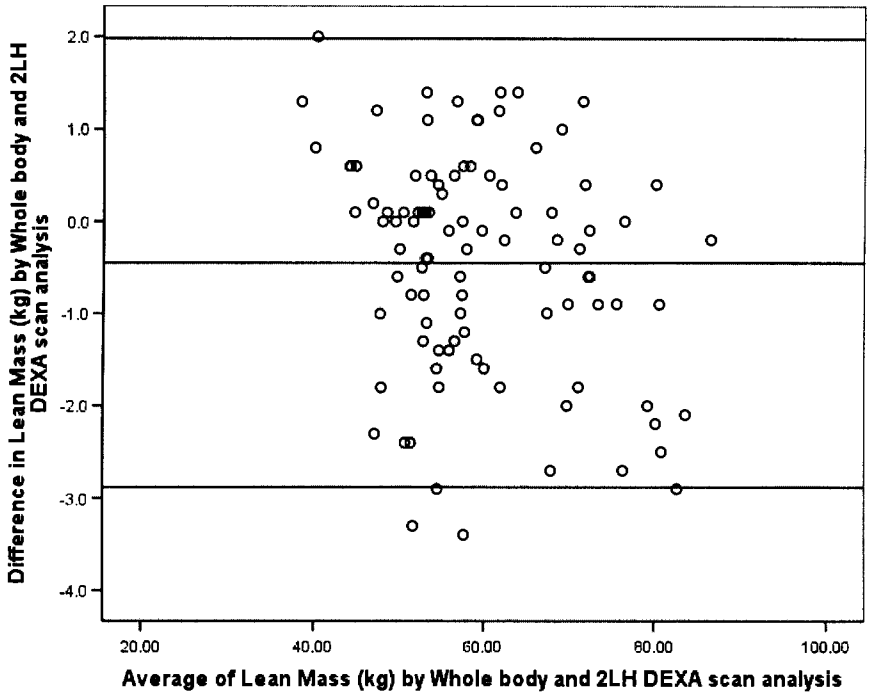


Figure 21. Lower and upper limits of agreement (mean difference ± 2SD) for whole body and right half-body DEXA analyses for bone mineral content.

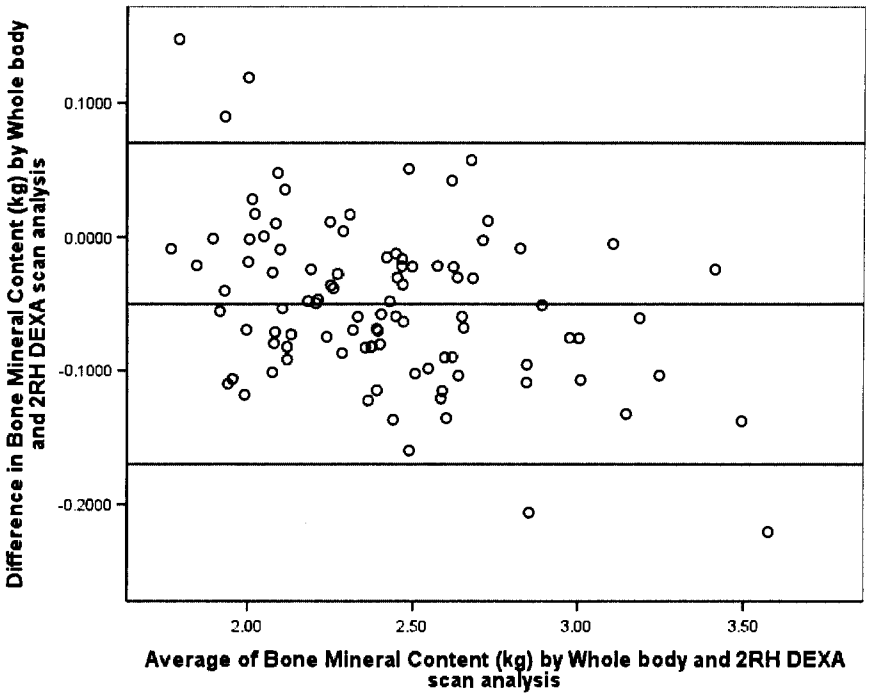
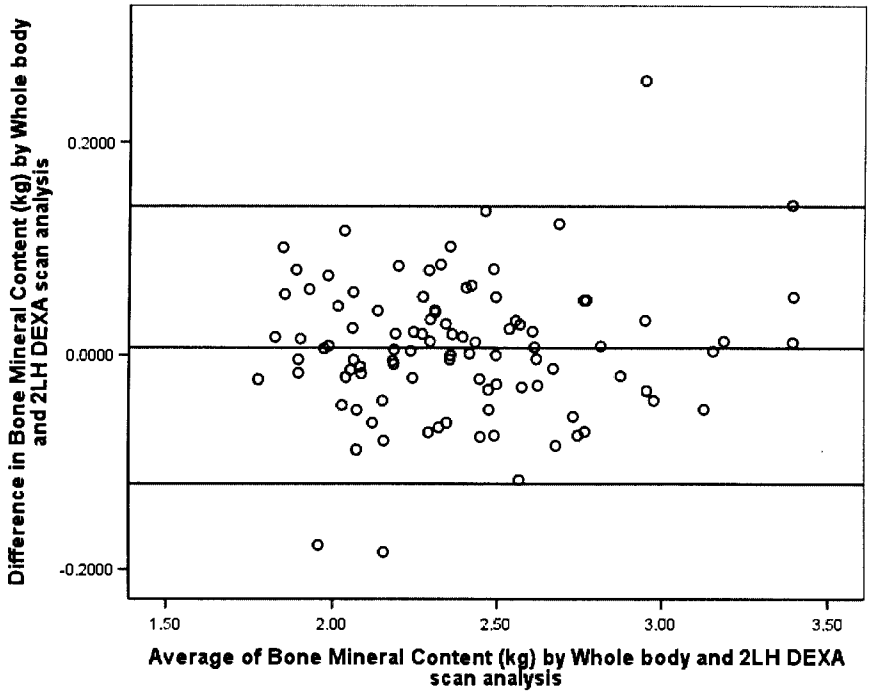


Figure 22. Lower and upper limits of agreement (mean difference ± 2SD) for whole body and left half-body DEXA analyses for bone mineral content.



SUMMARY AND CONCLUSIONS

This prospective cross-sectional study compared three body composition techniques, traditional whole body DEXA scan analysis, regional left and right half-body DEXA scan analyses, and BIA, to measure fat mass, lean mass, bone mineral content, fat-free mass, and percent body fat in obese individuals. Study participants were obese (BMI 30-50 kg/m^2) but met the manufacturer's weight, height and width criteria and fit completely within the scanning area of the DEXA table. The primary goal of this study was to determine whether half-body DEXA scan analyses were similar to the whole body DEXA scan analysis so that this analytical technique could be applied to those individuals who met the weight criteria but could not be scanned using the traditional, whole body DEXA method. A secondary goal was to compare body composition parameters measured by whole body DEXA scan analysis to BIA. The tertiary goal of this study was to explore variables (age, gender, weight, height, and BMI) that may predict differences in body composition parameters between body composition techniques.

The first study hypothesis was accepted; the mean differences and confidence interval width for whole body DEXA scan analysis and left and right half-body DEXA scan analysis for fat and lean mass were less than 1 kg. As reported by Lohman and colleagues (68), a mean difference of 1 kg between body composition methods is considered good agreement between the methods studied. Although all but one p-value for the mean differences were statistically significant, the magnitude of the mean differences were not clinically different. The lower and upper confidence interval values for the mean differences were small as well. For example, when fat mass was measured

by whole body DEXA and the right half-body DEXA method, the lower confidence interval was –1.29 kg and the upper confidence interval value was 1.76 kg. When measuring an obese individual who weighs approximately 100 kg, a possible difference between –1.29 and 1.76 kg is not considered significant.

In this study, mean differences between techniques were less than 0.6 kilograms for all parameters, which suggests excellent agreement. Additionally, agreement between body composition methods was observed with the Bland-Altman method. By analyzing both mean differences and agreement, the methods were appropriately analyzed. The small differences in body composition methods observed may be due to error that occurs with multiple DEXA measurements as reported by the coefficient of variations, rather than error directly from the half-body DEXA method.

To compare two measurements using a Hologic QDR 4500/W scanner within the same participants, Litaker and colleagues (53) calculated limits of agreement and interval width for the limits of agreement in 219 adolescent males and females. The largest interval width difference that was calculated was 3.1% for percent body fat, compared to differences of 1.72% and 1.66% between whole body and right and left half-body DEXA analyses, respectively, presented in this study. The largest confidence interval width of differences presented in this study for measurements by whole body and half-body DEXA was 4.97 kg for fat-free mass. The intervals for this study may be different because the measurements were performed on obese adults, rather than adolescents. The sample sizes also differed (98 versus 219), and if the samples were similar in size, the interval width for fat mass and fat-free mass in this study may also be smaller.

Heymsfield and colleagues (21) described the applications of DEXA, specifically to individuals who did not fit within the DEXA scanning area. The authors recommended following the conclusions of Tataranni and Ravussin (63), which were to scan the right side of the body to estimate whole body composition assuming bilateral symmetry. The study by Tataranni and Ravussin is the only study reported in the current literature that has analyzed half-body DEXA scans of 17 obese adults who exceed the DEXA scanning table dimensions. These researchers performed two DEXA scans, one of the right half-body and one of the left half-body using a pencil beam DEXA machine. The data from these two scans were added together and the sum was compared to body composition estimated by hydrodensitometry in 17 individuals who did not fit within the DEXA scanning area. Six individuals could not complete the study because of extreme discomfort while lying down on the DEXA table and four other participants could not perform hydrodensitometry. Of the 17 individuals who completed both measurements, no significant differences in body compartments were found between the left and right halves of the body. The error in predicting body composition by half-body DEXA scans were not affected by the subject's body size and/or scanning technique. Researchers concluded that the results from half-body scans accurately predict whole body composition.

The study performed by Tataranni and Ravussin differed from the current study in that it reported on fewer participants (17 versus 98 individuals) and used a pencil beam DEXA machine rather than a fan beam DEXA machine. As mentioned earlier, the pencil beam DEXA takes more time to perform and can be less precise in measuring body composition. Tataranni and Ravussin also used two scans, one scan of the left half of the

body and a second scan of the right half of the body, and added the two scan results together to compare to the whole body measurement by hydrodensitometry. The current study used only one whole body DEXA scan, which requires less time for the participant and less time for the DEXA technician to perform the scan. One scan also exposes the participant to less radiation.

BIA slightly overestimated fat mass by 2.31 kg and underestimated fat-free mass by 1.85 compared to the whole body DEXA scan analysis. This is different than what has been reported when measuring body composition using BIA in obese individuals (1, 18). In previous studies, fat-free mass was overestimated and fat mass was underestimated presumably due to their altered hydration status (1, 18). However, to account for the potential error due to altered hydration, this study used body fat- and gender-specific prediction equations rather than the manufacturer's proprietary equation to more accurately predict the body composition of the obese sample. The hypothesis that fat and fat-free mass have a mean difference equal to or less than 1 kg when measured by whole body DEXA scan analysis and BIA, was rejected. Mean differences between the whole body DEXA measurement and BIA measurement were small considering the total mass of the individuals being measured in this study (average 103 ± 13 kg). Even though there were statistically significant differences between body composition parameters measured by whole body DEXA and BIA and the mean differences for fat mass, fat-free mass and percent body fat were greater than 1 kg, the mean differences were not considered clinically significant. The largest mean difference was 2.31 kg for fat mass, which is about 2.2% of the average body weight for the participants in this study. These values suggest that under these conditions BIA is an

effective body composition measurement tool particularly if a body fat specific prediction equation like the one established by Segal and colleagues (17) is used.

The tertiary goal was to explore variables that predict differences in the body composition techniques for each body composition parameter. Univariate and multivariate regression models were used to determine whether weight, height, BMI, sex or age predicted differences in body composition methods. Since there were no trends observed in either the univariate or multivariate models, the regression analysis did not provide any further information about the differences.

Strengths of Study Design

One strength of this study is the sample size. This study was able to measure ninety-eight healthy obese individuals who did fit within the DEXA scanning area and met all other criteria. The study was able to measure participants with a wide range of body mass indices and ages. The DEXA machine used in this study was one of the most current machines available by Hologic, Inc. It uses fan beam technology, which produces higher resolution images and is more precise in body composition measurement compared to pencil beam technology (50, 53). Participants were exposed to less radiation and there was less measurement error due to a single DEXA scan compared to two DEXA scans used in the Tataranni and Ravussin study (63). Body fat and gender-specific BIA equations were used to eliminate error when calculating fat-free mass, and is more appropriate than using the non-specific manufacturer's equation (48). The study used trained and licensed technicians to perform all scans.

Limitations

There are limitations to this research as well. This research used an assumption based on current research that DEXA is the "gold standard" and used DEXA as the standard for comparison. This is a limitation due to the limitations and assumptions of DEXA when measuring body composition. One problem associated with DEXA and BIA is that body composition measurements become less accurate as tissue mass increases. With BIA, as tissue mass increases, total body water increases and extracellular water volume is greater than intracellular water compartments compared to normal (18). With DEXA, as tissue mass increases, the radiation sent through the body and into the C-arm receiver is distorted and can affect the measurement outcome.

Specific to the DEXA half-body scan analysis, there is error with the DEXA technician's ability to place the sagittal line for the half-body DEXA scan analyses. If the technician is inexperienced in placing this line, it may not be as accurate and may introduce error into each analysis. Technicians must be familiar with anatomical reference points and be able to generate a straight line down the center of the participant's body.

This study is limited to the population studied. Therefore, in individuals with significantly asymmetrical bodies as seen with cerebral palsy or amputations, the half-body DEXA scan analysis would not necessarily be an accurate reflection of whole body composition. It has been reported that BIA is an accurate measure of fat-free mass in individuals with cerebral palsy, but that body fat measured by BIA is less accurate (69). Half-body DEXA scan analysis is not applicable to those who exceed the manufacturer's

weight limit, since these individuals cannot be scanned. Therefore, another method to measure body composition in heavier individuals must be used.

This study did not include individuals who did not fit completely within the DEXA scanning plane. The results of this study may be different if it included only those who required a half-body DEXA scan and the results from this study may not apply to these individuals. This would have to compare the half-body DEXA scan analysis to another body composition method as done by Tataranni and Ravussin (63). The participants in this study were predominantly white. It would not be appropriate to apply these results to a mixed-ethnicity population since multiple studies have shown differences in bone mineral content, bone density and muscle density between different ethnicities (21, 30 - 34). Differences due to ethnicity were not examined in this analysis since there were only five nonwhite participants.

This study used a Hologic Discovery A DEXA machine for the DEXA analyses. Results may be different for other models or manufacturers as seen in the study by Litaker et al (53). Validation of the half-body DEXA scan analysis with an older model where the weight limit is less than 350 pounds is warranted. However, some of the older software may not be capable of analyzing half-body regions. To utilize half-body DEXA analysis in the obese population research facilities need to explore their software options and discuss these options with their DEXA manufacturer representative.

To eliminate error in body composition measurements by BIA, body fat and gender-specific prediction equations were used (17). The equations were used in a similar population as the current study cohort. The equations were validated in a large sample (n = 1567) of obese men and women, with a wide range of ages. The results

reported in the current study, however, are specific to the BIA machine used and could not be applied if a different BIA equation or the manufacturer's proprietary equation were used. The BIA machine used in this study was a single frequency analyzer (50 kHz). Single frequency analyzers may not be accurate when used for measuring total body water of obese individuals due to the altered electrical properties of their tissues which do not allow for complete penetration of the electrical current (42, 67, 69). A multiple frequency analyzer may be more accurate because extracellular water can be differentiated from total body water, which is measured at the higher frequencies. Measuring water distribution between intracellular and extracellular spaces can be informative for fluid shifts in obese individuals participating in weight loss interventions or in bariatric surgery patients.

Future Research

Further research is needed to validate body composition techniques to assess obese individuals who do not meet the current weight and body size criteria established by DEXA machine manufacturers. Research is also warranted to compare body composition parameters in obese individuals before and after significant weight loss to determine the differential effects of various weight loss interventions whether they are dietary, surgical, drug or exercise based. Research using DEXA would help to determine whether prediction or diagnosis of osteoporosis would be accurate in obese elderly given the distortion and inability to use whole body t- and z-scores for diagnosis. This research is essential since the majority of the population is getting larger, more individuals are living longer and the impact of obesity on bone health is still unknown. If DEXA has

been used in previous research to assess bone health in obese individuals, there could be the chance that the spine, hip and femoral neck scans were distorted as a result of a thicker trunk area, and larger mass overall, thereby potentially leading to false statements about obese individuals and bone density or bone health.

SUMMARY

Even though the mean differences between whole body and half-body DEXA methods were statistically significant for the majority of body composition parameters measured, these differences were not considered clinically significant. Half-body DEXA scan analysis may be used as an appropriate method to measure body composition parameters in obese individuals who meet the weight and height criteria, but exceed the scanning area of the machine. Additionally, validation of this method, as well as other body composition methods, in the obese populations needs to be performed. As the obesity rates in the United States population continue to rise, more accurate techniques to measure body composition in these individuals needs to be developed.

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APPENDIX A

Oregon Health & Science University
Consent Form

eIRB#: 777

Protocol Approval Date: 01/20/2005

OREGON HEALTH & SCIENCE UNIVERSITY
Consent Form

TITLE: *Metabolic Consequences of Low and High Carbohydrate Diets: The Insight Weight Loss Study*

PRINCIPAL INVESTIGATOR:	Diane Stadler, PhD, RD	(503) 494-0168
CO-INVESTIGATORS:	Njeri Karanja, PhD	(503) 335-2417
	Glenn Gerhard, MD, PhD	(503) 494-2008
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	William Connor, MD	(503) 494-2001
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	Rebecca Kitterman, RD	(503) 494-4786
	Whitney Silverstein, BS	(503) 494-4786
	Angela Horgan, PhD, RD	(503) 494-6231

SPONSOR: National Center for Complementary and Alternative Medicine, National Institutes of Health

PURPOSE:
You have been invited to be in this study at OHSU because you are enrolled in the Insight Weight Loss Study conducted by the Kaiser Permanente Center for Health Research. The purpose of the Insight Weight Loss Study is to compare the effects of the ATKINS diet (low-carbohydrate) and the DASH diet (high-carbohydrate) on weight loss, maintenance of weight loss, and overall health.

Up to 250 participants will be enrolled into the Insight Weight Loss Study and randomly assigned (assigned by chance) to follow either the Atkins-style diet or the DASH-style diet. Each participant will be enrolled in the study for 30 months and will attend three visits at the OHSU General Clinical Research Center (GCRC) to complete study related measurements. All participants, regardless of the group they are in, will complete a standard set of study measurements before they start the dietary intervention and again 6-months and 30-months after they start the dietary intervention. Each set of standard measurements takes about two hours to complete. In addition to completing the three standard measurement sets, 36 participants will be randomly selected to participate in the

Resting Energy Expenditure Subsample. A different set of 48 participants will be randomly selected to participate in the Meal Tolerance Subsample.

PROCEDURES:
During each of the three visits to the General Clinical Research Center at OHSU you will be asked to complete the:
Standard Measurement Set:

- Arrive in the morning before you have eaten breakfast or any other food or beverage, except water, and before you have participated in any significant physical activity or exercise.
- Return your completed Quality of Life questionnaire distributed by the KPCHR study staff or, if necessary, complete the questionnaire at OHSU. This form may take up to 30 minutes to complete. This questionnaire contains about 130 questions and asks about nutrition-related issues and dieting and emotional well-being, vitality, general health status, sleep quality, daily function and work activity.
- Return all of the urine you collected during the past 24 hours into the container(s) provided to you by Kaiser Permanente Center for Health Research staff. If urine was spilled or if you forgot to collect some of your urine, you may be asked to repeat the collection and return it to the GCRC.
- Provide a urine sample for a pregnancy test if you are female. The results of the urine pregnancy test will remain private. We will inform you of the results and, if positive, refer you to your regular doctor or health care provider for on going care.
- Have your weight height, and waist circumference measured. This process will take about 10 minutes.
- Have your body composition (the amount of lean and fat tissue in your body) measured with a whole body scan using a DEXA machine. This process will take about 10 minutes. You will be asked to remove any clothing or jewelry that contains metal (for example, metal snaps, clasps, buckles, rings, ear-rings, etc). This procedure can only be performed if you weight less than 340 pounds and are less than 6'2" tall.
- Have your body composition measured by bioelectrical impedance. This process involves passing a very small, unperceivable electrical current between sets of electrodes attached to removable adhesive pads placed temporarily near your ankle and near your wrist. This is a painless, risk-free process that takes less than one minute to complete.
- Have your blood pressure measured twice after resting for 5 minutes. This step takes about 8 minutes.
- Provide a fasting blood sample of about four tablespoons from an arm vein. This step takes about 5 minutes to complete
- For those completing the standard measurement set, only, a breakfast meal will be provided after all measurements are done. You should plan to spend about 2 hours in the GCRC at each visit to complete the "Standard Measurement Set".

Resting Energy Expenditure Measurement:

If you are assigned to the resting energy expenditure subsample, you will complete the standard measurement set plus you will have your energy expenditure (calorie use) measured while you rest. This process takes about 1 hour to complete. A lightweight, clear, Plexiglas canopy will be placed over your head and chest so that samples of the air that you breathe out can be collected and analyzed. A trained research assistant will perform these procedures in a private room and care will be taken to maximize your comfort and feelings of relaxation. A breakfast meal will be provided after all measurements have been completed. You should plan to spend about three hours in the GCRC at each visit to complete all study related measurements.

Meal Tolerance Subsample:

If you are assigned to the meal tolerance subsample, you will be admitted to the inpatient unit of the GCRC the morning of or the evening before this set of measurements. If you are schedule for these measurements on a weekday, you will complete the standard measurement set in addition to the meal tolerance procedure. If you are scheduled for the meal tolerance procedure on a weekend day, you will complete the blood sampling procedures only and the standard measurement set will be scheduled within 2 weeks on a weekday.

During the meal tolerance procedure, you will have a blood-sampling catheter inserted into one of your arm veins between 8:00-8:30 am and this catheter will remain inserted in your arm for up to nine hours. Blood samples of about 1 ½ tablespoon each will be collected before you eat a GCRC prepared breakfast meal and again ½, 1, 1 ½, 2, 2 ½, 3, 3 ½, 4, 6, and 8 hours after eating the breakfast meal (about 16 ½ tablespoons of blood in total). After the last blood sample has been taken, the blood drawing catheter will be removed from your arm. You will be allowed to drink water during the blood collection procedure but you will be asked not to eat until after the last blood sample is collected. A lunch/dinner meal will be provided to you at the end of the procedure.

In between the three regularly scheduled OHSU visits, you may be asked to return to the GCRC for additional safety monitoring at the discretion of the study investigators. These visit(s) may include:

- Drawing additional blood samples of about one tablespoon total.
- Having a physical examination performed by one of the study physicians or their designee.
- Participating in an interview to review your medical history with one of the study physicians or their designee.

If you have any questions about the measurements taken at OHSU for the Insight Weight Loss Study, now or in the future, contact Diane Stadler at (503) 494-0168.

RISKS AND DISCOMFORTS:

Blood sampling will be performed by a registered nurse or a trained phlebotomistfor those providing a fasting blood sample, only. A registered nurse will insert and draw blood from the blood sampling catheter inserted into an arm vein for those in the Meal

Tolerance Subsample. You may feel some pain when your blood is drawn or when the blood sampling catheter is inserted. There is a small chance the needle will cause bleeding, a bruise, or an infection. There is also a small chance that part way through the meal tolerance test, the blood sampling catheter will stop working and that a new blood sampling catheter will need to be inserted into a vein in your other arm.

As a result of the total body DEXA scan performed in this study you will be exposed to some radiation (x-rays). The body scan provides about the same exposure to x-rays as a cross-country airplane flight. While no amount of radiation has been proven to be safe, there is no direct evidence that small doses of radiation, similar to those used in the body scan, cause harmful effects in the persons who are exposed.

There is no risk involved with having body composition analyzed by bioelectrical impedance.

There are no risks associated with having resting energy expenditure measured using a canopy air-collection system. However, some people report feeling claustrophobic or "closed-in".

The Quality of Life Questionnaire includes questions about the hassles associated with following a specific diet, nutritional health perceptions, and nutrition and social function. Some of these questions may seem very personal or embarrassing. They may upset you. You may refuse to answer any of the questions that you do not wish to answer. If the questions make you very upset, we will help you to find a counselor.

BENEFITS:
You may or may not personally benefit from being in this study. However, by serving as a subject, you may help us learn how to benefit patients in the future. Laboratory tests will be performed at no cost. You will be informed of any clinically significant abnormalities and these abnormal laboratory results will be provided to your physician upon your request.

ALTERNATIVES:
You may choose not to participate in any or all of the measurements taken in the General Clinical Research Center at OHSU. If you choose not to participate, you may be asked to withdraw from the Insight Weight Loss Study conducted by the Kaiser Permanente Center for Health Research.

CONFIDENTIALITY:
We will not use your name or your identity for publication or publicity purposes. To have blood samples taken and analyzed at OHSU as part of this study you must have an OHSU medical record number. If you did not already have an OHSU medical record number, one was assigned to you as part of the GCRC scheduling process. To ensure that the medical record number assigned to you is unique, that this number has not been, or will not be, assigned to anyone else, you were asked to provide two forms of personal information such as your social security number and your mother's maiden name. Your OHSU medical record number will be provided to authorized data management staff at

the Kaiser Permanente Center for Health Research. The data management staff will use your OHSU medical record number to identify your study-related blood sample results, only. All other OHSU measurement results will be transferred to the data management staff at the Kaiser Permanente Center for Health Research but this information will be labeled with the unique study code assigned by the Center for Health Research, only. Some of the blood samples collected at OHSU will be sent to the University of Colorado Health Sciences Center, the University of California-Los Angeles, Pacific Biometrics, Inc or LipoScience, Inc for analysis. Some urine samples collected at OHSU will be sent to the University of Iowa Hospital and Clinics for analysis. Blood and urine samples sent to the University of Colorado Health Sciences Center or the University of Iowa Hospital and Clinics will be labeled with the unique study code assigned by the Center for Health Research, only.

Research records may be reviewed and/or copied by the sponsor of the study, the OHSU Institutional Review Board, the Office for Human Research Protections, the OHSU General Clinical Research Center, the National Center for Research Resources, the OHSU Laboratory and its contracted subsidiaries as required by law.

COSTS:
There are no costs associated with having measurements taken at OHSU for the Insight Weight Loss Study. All costs associated with collecting and analyzing the blood and urine samples and performing the body composition, resting energy expenditure, and meal tolerance measurements will be paid for by the study. You are not offered payment for being in this study.

LIABILITY:
If you believe you have been injured or harmed while participating in this part of the research study and require immediate treatment, contact Diane Stadler, PhD at (503) 494-0168.

It is not the policy of the U.S. Department of Health and Human Services, or any federal agency funding the research project in which you are participating, to compensate or provide medical treatment for human subjects in the event the research results in physical injury.

The Oregon Health & Science University is subject to the Oregon Tort Claims Act (ORS 30.260 through 30.300). If you suffer any injury and damage from this research project through the fault of the University, its officers or employees, you have the right to bring legal action against the University to recover the damage done to you subject to the limitations and conditions of the Oregon Tort Claims Act. You have not waived your legal rights by signing this form. For clarification on this subject, or if you have further questions, please call the OHSU Research Integrity Office at (503) 494-7887.

PARTICIPATION:
If you have any questions regarding your rights as a research subject, you may contact the OHSU Research Integrity Office at (503) 494-7887. You do not have to join this or any research study. If you do join, and later change your mind, you may quit at any time. If

you refuse to join or withdraw early from this part of the study, there will be no penalty or loss of any benefits to which you are otherwise entitled.

If you are a student or employee at OHSU, your participation in this research project is completely voluntary. You are free to choose not to serve as a research subject in this protocol for any reason. If you do elect to participate in this study, you may withdraw from the study at any time without affecting your relationship with OHSU, the investigator, the investigator's department, or your grade in any course. If you choose to withdraw from the study during your OHSU visit, we will request that you attend a final study interview at the Kaiser Permanente Center for Health Research.

Dr. Stadler or Dr. Gerhard may withdraw you from the measurements done at OHSU at any time if they believe it is in your best interest or if you are unable to follow instructions or complete the procedures. We will inform you of any new findings that may affect your willingness to continue or to withdraw from this part of the Insight Weight Loss Study.

SIGNATURES:
Your signature below indicates that you have read this entire form and agree to participate in this study. We will give you a copy of this signed consent form.

OREGON HEALTH & SCIENCE UNIVERSITY
INSTITUTIONAL REVIEW BOARD

PHONE NUMBER (503) 494-7887

CONSENT/AUTHORIZATION FORM APPROVAL DATE

Jul. 18, 2005

Do not sign this form after the Expiration date of: 1/19/2006

_____ _____
Subject's signature Date

_____ _____
Investigator's signature Date

APPENDIX B

Version: _____

OHSU Oregon Health & Science University

HIPAA RESEARCH AUTHORIZATION

AUTHORIZATION FOR THE CREATION, USE, AND DISCLOSURE OF PROTECTED HEALTH INFORMATION FOR INSTITUTIONAL REVIEW BOARD APPROVED RESEARCH

Title of Study:	Metabolic Consequences of Low and High Carbohydrate Diets (aka, Insight Weight Loss Study)
Name of Investigator:	Diane Stadler, PhD, RD
Phone Number:	503-494-0168
Sponsor:	NIH: NCCAM
IRB Number:	777
Protocol Approval Date:	1/20/2005
Consent Form Approval Date:	

This authorization is voluntary, and you may refuse to sign this authorization. If you refuse to sign this authorization, your health care and relationship with OHSU will not be affected. However, you will not be able to enter this research study.

1. This form authorizes Oregon Health & Science University (OHSU) to use and disclose (release) certain protected health information about _____ (name of subject) that we will collect and create in this research study. The description of the information to be used or disclosed and the purposes of the requested use or disclosure are indicated in item number 8 of the authorization form.

2. The persons who are authorized to use and disclose your protected health information are:
   - ☒ All investigators listed on page one of the Research Consent Form
   - ☒ Others at OHSU who are participating in the conduct of this research protocol
   - ☒ The OHSU Institutional Review Board
   - ☐ Others: _____

3. The persons who are authorized to receive this information are:
   - ☒ The sponsor of this study: NIH; National Center for Complementary and Alternative Medicine
   - ☒ Federal or other governmental agencies as required for their research oversight and public health reporting in connection with this research study:
     ☒ OHRP ☐ FDA ☐ Other: _____
   - ☒ Others: Kaiser Permanente Northwest Center for Health Research
     University of Colorado Health Sciences Center
     University of Iowa Hospital and Clinics
     OHSU laboratories and its contracted subsidiaries

4. We may continue to use and disclose protected health information that we collect from you in this study until:
   - ☐ HIPAA Research Authorization expiration date _____
   - -OR-
   - ☐ The study is completed _____
   - ☐ Indefinitely
   - ☒ Other: Five years after the IRB has accepted thefinal report as required by NIH

5. While this study is still in progress, you may not be given access to medical information about you that is related to the study. After the study is completed and the results have been analyzed, you will be permitted access to any medical information collected about you in the study.

Document Control No.: IRB-HRA-01-09
Original Date: 03/25/2003; Revision Date: 09/21/2004

6. You have the right to revoke this authorization and can withdraw your permission for us to use your information for this research by sending a written request to the Principal Investigator listed on page one of the research consent form. If you do send a letter to the Principal Investigator, the use and disclosure of your protected health information will stop as of the date he/she receives your request. However, the Principal Investigator is allowed to use and disclose information collected before the date of the letter or collected in good faith before your letter arrives. If you withdraw any tissue or blood samples that were collected from you, they either will be destroyed or stored without any information that identifies you. Revoking this authorization will not affect your health care or your relationship with OHSU.

7. The information about you that is used or disclosed in this study may be re-disclosed and no longer protected under federal law. However, Oregon law restricts re-disclosure of HIV/AIDS information; mental health information; genetic information; and drug/alcohol diagnosis, treatment, or referral information.

8. Description of the information to be used or disclosed and the purposes of the requested use or disclosure:

HEALTH INFORMATION *(Check as applicable)*	**PURPOSE(S)** *(Enter corresponding letter(s) from Purpose Categories)*
☐ Your complete existing health record **	____
☐ Limited information from your existing health record** (specify): ____	____
** If we are requesting existing health records that are located outside of OHSU, you will need to complete an additional authorization to release these records to OHSU.	
THE FOLLOWING CHECKED ITEM(S) WILL BE GENERATED/COLLECTED DURING THE COURSE OF THIS STUDY:	
☐ History and physical examinations	____
Reports: ☒ Laboratory ☐ Operative ☐ Discharge ☐ Progress	a, f
☐ Photographs, videotapes, or digital or other images	____
☒ Diagnostic images/X-ray/MRI/CT	a
☐ Bioelectric Output (e.g., EEG, EKG)	____
☒ Questionnaires, interview results, focus group survey, psychology survey, behavioral performance tests (e.g., memory & attention)	a, f
☒ Tissue and/or blood specimens	a, f
☒ Other: urine samples, OHSU medical record number	a, f f

PURPOSE CATEGORIES

a. To learn more about the condition/disease being studied
b. To facilitate treatment, payment, and operations related to the study
c. To comply with federal or other governmental agency regulations
d. For teaching purposes
e. To place in a repository or information/tissue "bank."
f. Other fTo analyze research results

Document Control No.: IRB-HRA-01-09
Original Date: 03/25/2003; Revision Date: 09/21/2004

9. If the information to be used or disclosed contains any of the types of records or information listed just below, additional laws relating to use and disclosure of the information may apply. You understand and agree that this information will be used and disclosed only if you **place your INITIALS** in the applicable space next to the type of information.

N/A Acquired immunodeficiency syndrome (AIDS) or human immunodeficiency virus (HIV) infection information
N/A Drug/alcohol diagnosis, treatment, or referral information
N/A Mental or behavioral health or psychiatric care
N/A Genetic testing information

You will receive a copy of this authorization form after you sign it.

Printed name of Research Subject

Signature of Subject Date

-OR-

Printed name of Subject's Legally Authorized Representative

Signature of Subject's Legally Authorized Representative Date

Description of Relationship to Subject:

OREGON HEALTH & SCIENCE UNIVERSITY
INSTITUTIONAL REVIEW BOARD
PHONE NUMBER (503) 494-7887
CONSENT/AUTHORIZATION FORM APPROVAL DATE

Feb. 22, 2005

Do not sign this form after the
Expiration date of: 1/19/2006

Document Control No.: IRB-HRA-01-09
Original Date: 03/25/2003; Revision Date: 09/21/2004

APPENDIX C: PRELIMINARY DATA

Measuring body composition in obese individuals can be difficult due to the altered hydration status, large size, proportion and distribution of fat mass. Altered hydration status in obese individuals can affect measurements by BIA, and large size as well as the proportion and distribution of fat mass can affect DEXA measurements. Many obese individuals do not fit within the DEXA scanning area. Within the first phase of the Comparison of health benefits and risks of high carbohydrate/low fat or very low carbohydrate diets for weight loss study, some subjects did not fit within the DEXA scanning area, thus no DEXA measurement was taken of these participants. For these reasons, alternative methods should be explored. One proposed alternative method is a half-body DEXA scan analysis multiplied by two to achieve whole body composition.

Retrospective analysis of data from the *Comparison of health benefits and risks of high carbohydrate/low fat or very low carbohydrate diets for weight loss study* was conducted to compare body composition techniques when measuring obese individuals before weight loss. Fat-free mass, fat mass, and bone mass was measured in 15 obese adults using traditional whole body DEXA scan analysis, left- and right-half body DEXA scan analysis, BIA, and air displacement plethysmography (BODPOD) and were compared. Subjects were healthy obese men (n=4) and women (n=11), with body mass indices (BMI) of 30-50 kg/m^2. Data was excluded from the analysis if the participant weighed more than 159 kilograms, or if valid total body DEXA, BIA or BODPOD measurements were not available.

Height was measured using a stadiometer (Harpenden Stadiometer; Holtain Ltd; Crymych, UK) and body weight was measured with a digital scale (Scale-Tronix, Model

5002 Wheaton, IL) before eating breakfast, in light clothing, but without shoes. The 15 participants had an average weight of 101 kg, an average height of 168 cm, an average BMI of 36 and were 41 years old on average.

Body composition was measured by DEXA (QDR4500 Discovery A, Hologic, Inc., Bedford, MA), BIA (Body Composition Analyzer, Model 310e, Biodynamics Corp., Seattle, WA), and air displacement plethysmography (BODPOD, Life Measurement, Inc. Concord, CA) according to the manufacturer's instructions. DEXA scans were analyzed by a single research technician using traditional whole body assessment methodology and again using right and left half body assessment methodology [e.g., a sagittal line based on anatomical reference points (skull, spine, pelvis and legs) was positioned to distinguish left and right halves of the whole body scan]. For comparison purposes, all parameters from the half body assessments were multiplied by two.

The 95% CI suggests that the mean fat mass was greater by 0.34 to 1.08 kg and mean lean mass was greater by 0.12 to 1.36 when analyzed by the left half body DEXA method than by the whole body DEXA method (Table 1). Mean fat mass was less by 0.06 to 0.86 kg when analyzed by the right half body DEXA method compared to the whole body DEXA method (Table 1). However, mean lean mass was not different, when analyzed by the right half body DEXA method compared to the whole body DEXA method.

Total bone mineral content was not significantly different for either the left half body or right half body DEXA method compared to the whole body DEXA method as seen in Table 1. Compared to whole body DEXA analysis, BODPOD analysis overestimated fat mass by 3.11 to 7.61 kg and percent body fat 3.05 to 6.87%, and

underestimated fat-free mass by 2.80 to 6.88 kg in obese individuals (Table 2). Mean fat-free mass and fat mass were not significantly different when analyzed by DEXA and BIA methods (Table 2). Table 3 describes the correlations between whole body DEXA, two times the left and right half body DEXA, BIA and BODPOD with respect to fat-free mass, fat mass and percent body fat. All correlations were highly significant ($p<0.01$).

Figures 1, 2, and 3 display the means of fat-free mass, fat mass and percent body fat for all methods. The left half body DEXA scan analysis was significantly different from whole body DEXA and the right half body DEXA scan analyses for fat-free mass (Figure 1). Both the left and right half body DEXA scan analyses were significantly different from whole body DEXA for fat mass and percent body fat, but not different from BIA (Figures 2, 3). BODPOD was significantly different from whole body DEXA, right and left half body DEXA, and BIA for fat-free mass, fat mass and percent body fat (Figures 1,2,3).

The results from this preliminary analysis indicate a need for both the validity and accuracy of a half body DEXA analysis as well as alternative methods for body composition analysis in obese individuals. With an alternative, accurate method for body composition measurement, more research could be done to better understand obesity and its treatment and prevention. *Original abstract in Appendix E.*

Table 1. Comparison of body composition parameters by whole and half-body DEXA scans

		Mean Difference	*95% CI of Difference* Lower	Upper	*p-value*
Lean Mass (kg):	*WB-2LH*	*-0.74*	*-1.36*	*-0.12*	*<0.05*
	WB-2RH	*-0.02*	*-0.65*	*0.61*	*0.95*
Fat Mass (kg):	*WB-2LH*	*-0.71*	*-1.08*	*-0.34*	*<0.01*
	WB-2RH	*0.46*	*0.06*	*0.86*	*<0.05*
Bone Mineral Content (kg):	*WB-2LH*	*-0.01*	*-0.07*	*0.06*	*0.81*
	WB-2RH	*-0.03*	*-0.09*	*0.03*	*0.30*
% Body Fat	*WB-2LH*	*-0.22*	*-0.40*	*-0.04*	*<0.05*
	WB-2RH	*0.32*	*0.12*	*0.52*	*<0.01*

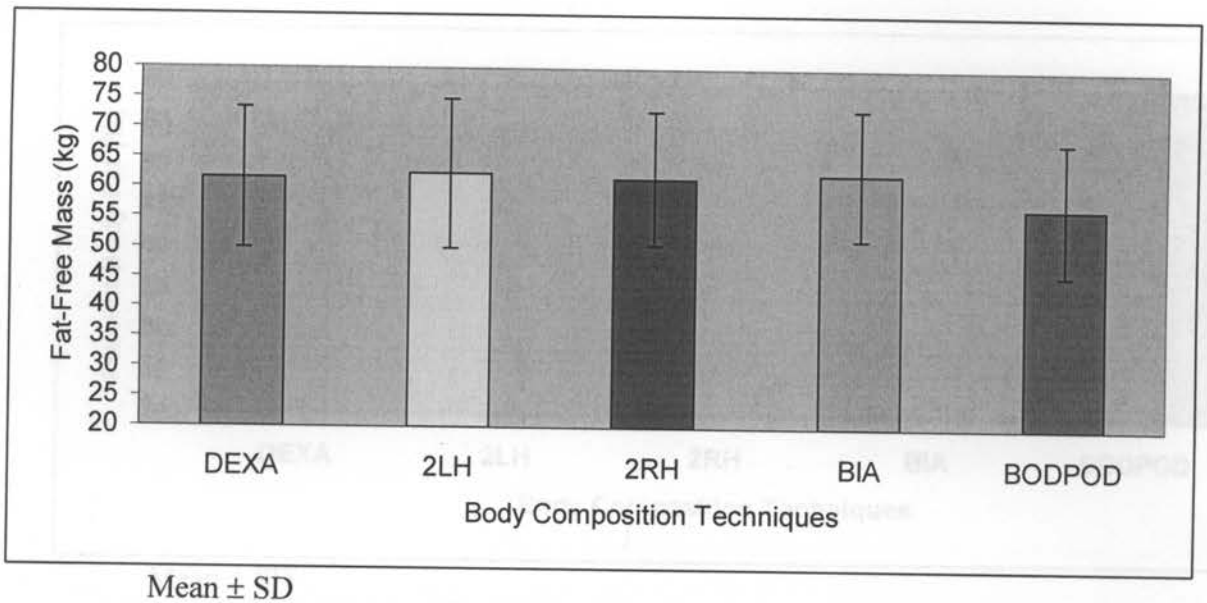
Table 2. Comparison of body composition parameters measured by DEXA, BIA, BODPOD ANALYSES

Fat-free mass (kg):	*DEXA-BIA*	*-0.75*	*-2.28*	*0.77*	*0.26*
	DEXA-BODPOD	*4.84*	*2.80*	*6.88*	*<0.01*
	BIA-BODPOD	*5.59*	*3.44*	*7.75*	*<0.01*
Fat Mass (kg):	*DEXA-BIA*	*-0.85*	*-2.39*	*0.70*	*0.81*
	DEXA-BODPOD	*-5.36*	*-7.61*	*-3.11*	*<0.01*
	BIA-BODPOD	*-4.51*	*-6.66*	*-2.37*	*<0.01*
% Body Fat	*DEXA-BIA*	*-0.17*	*-1.70*	*1.36*	*0.30*
	DEXA-BODPOD	*-4.96*	*-6.87*	*-3.05*	*<0.01*
	BIA-BODPOD	*-4.79*	*-6.81*	*-2.77*	*<0.01*

Table 3. Correlations of parameters between body composition methods

Correlations Between Body Composition Methods					
FAT-FREE MASS					
	DEXA	2LH	2RH	BIA	BODPOD
DEXA	1.000	0.997	0.996	0.973	0.949
2LH	0.997	1.000	0.985	0.972	0.938
2RH	0.996	0.985	1.000	0.968	0.953
BIA	0.973	0.972	0.968	1.000	0.937
BODPOD	0.949	0.938	0.953	0.937	1.000
FAT MASS					
	DEXA	2LH	2RH	BIA	BODPOD
DEXA	1.000	0.998	0.998	0.962	0.954
2LH	0.998	1.000	0.991	0.962	0.960
2RH	0.998	0.991	1.000	0.959	0.944
BIA	0.962	0.962	0.959	1.000	0.962
BODPOD	0.949	0.938	0.953	0.937	1.000
PERCENT BODY FAT					
	DEXA	2LH	2RH	BIA	BODPOD
DEXA	1.000	0.999	0.999	0.951	0.936
2LH	0.999	1.000	0.997	0.963	0.932
2RH	0.999	0.997	1.000	0.948	0.939
BIA	0.951	0.953	0.948	1.000	0.938
BODPOD	0.936	0.932	0.939	0.938	1.000

Figure 1. Fat-Free Mass as measured by body composition techniques



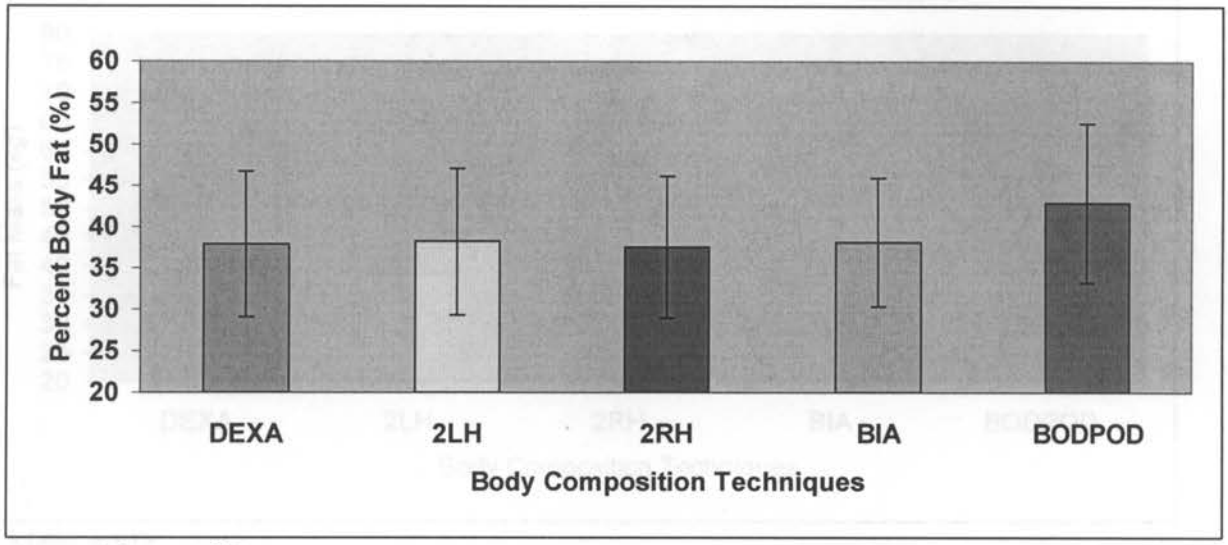
Mean ± SD

2LH significantly different from DEXA and 2RH

BODPOD significantly different from DEXA, 2LH, 2RH, and BIA

($p<0.05$)

Figure 2. Fat Mass as measured by body composition techniques



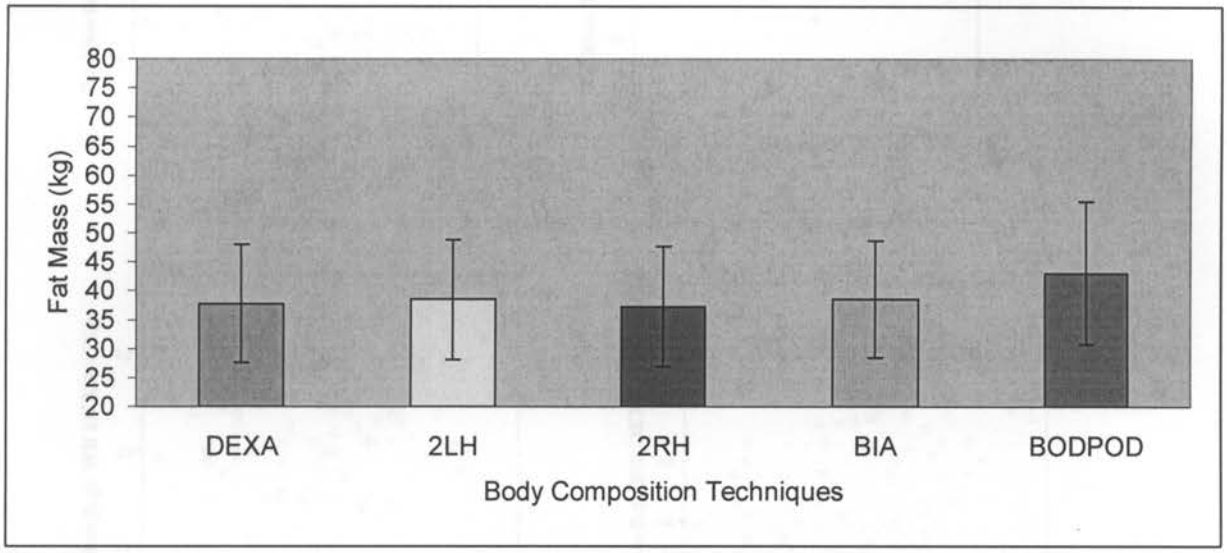
Mean ± SD

2LH and 2RH significantly different from DEXA

BODPOD significantly different from DEXA, 2LH, 2RH, and BIA

($p<0.05$)

Figure 3. Percent Body Fat as measured by body composition techniques



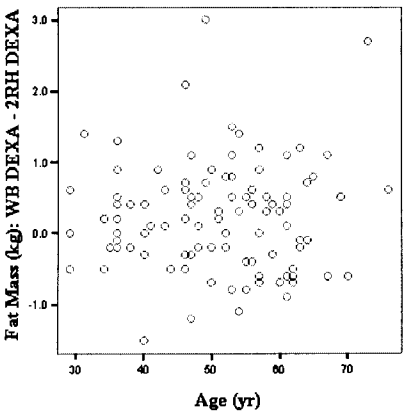
Mean ± SD
2LH and 2RH significantly different from DEXA

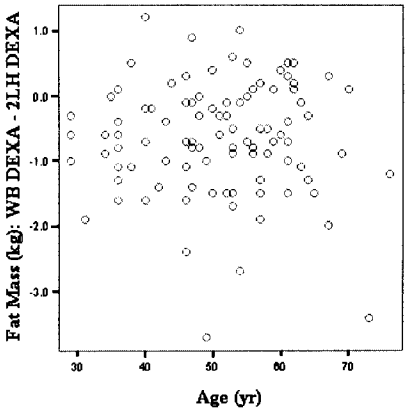
BODPOD significantly different from DEXA, 2LH, 2RH, and BIA

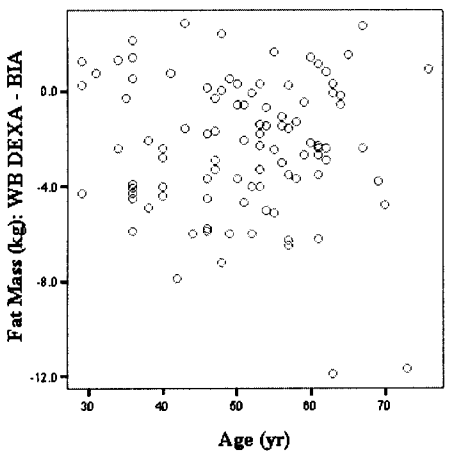
($p<0.05$)

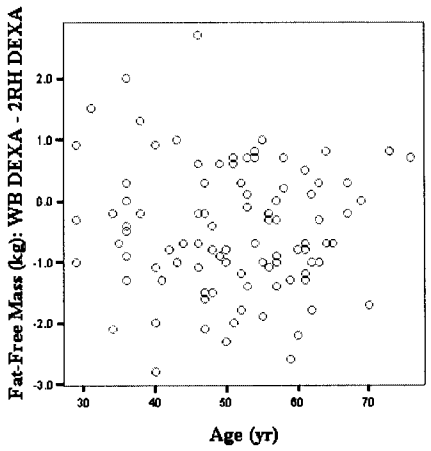
APPENDIX D: UNIVARIATE LINEAR REGRESSION SCATTERPLOTS

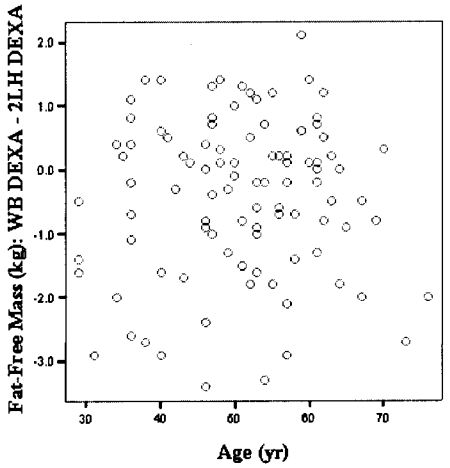
Figure 9. Age versus difference in whole body DEXA scan analysis, half-body DEXA scan analyses and BIA for each body composition parameter.











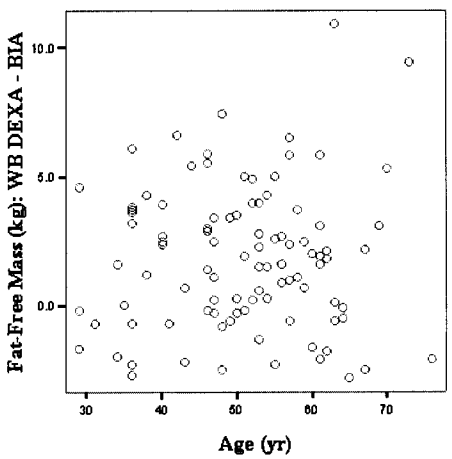
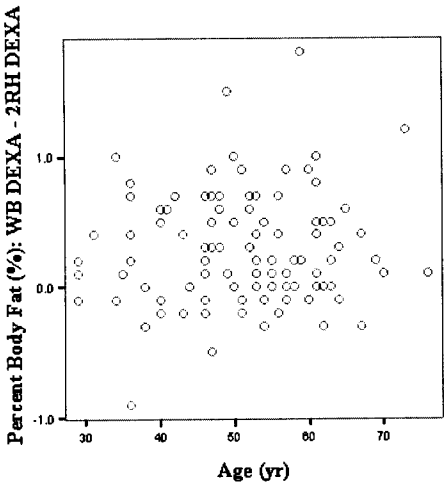
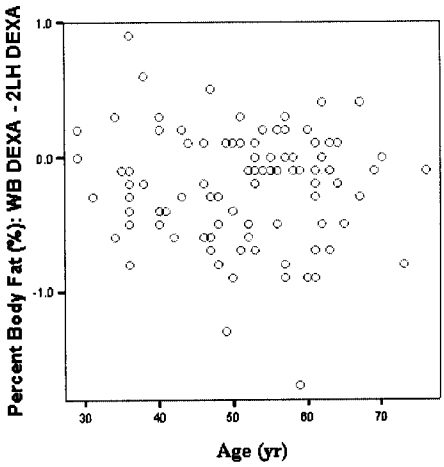
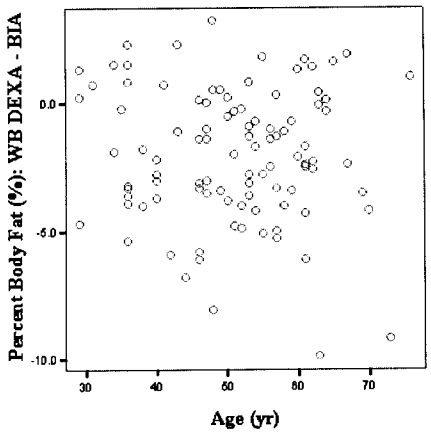
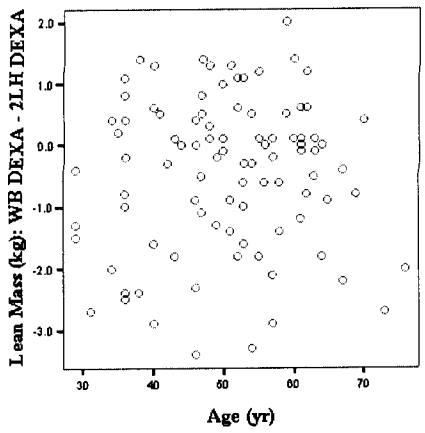


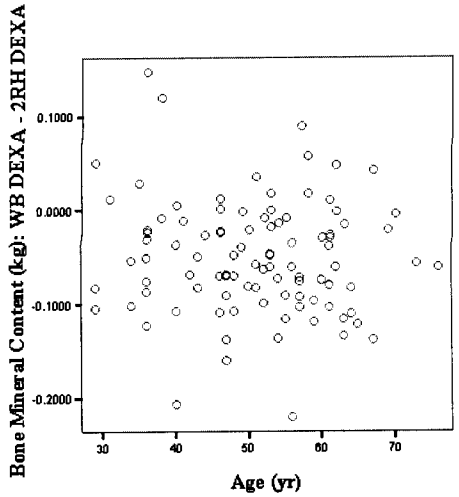
Figure 9. Age versus difference in whole body DEXA scan analysis, half-body DEXA scan analyses, and BIA for each body composition parameter.











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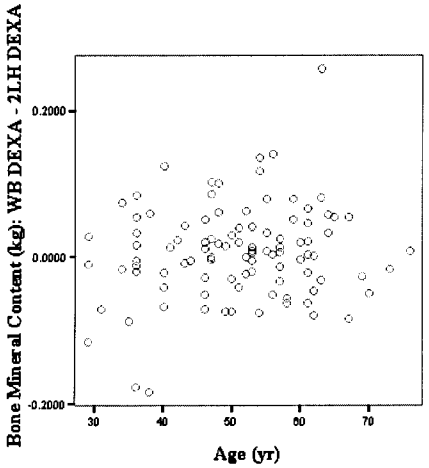
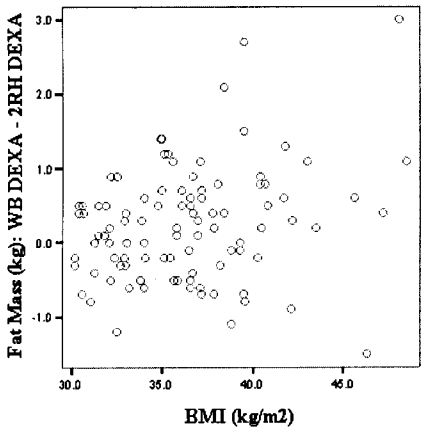
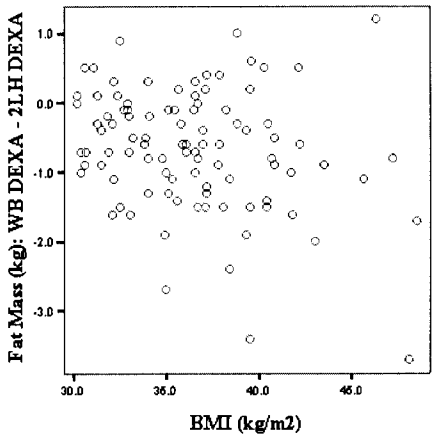
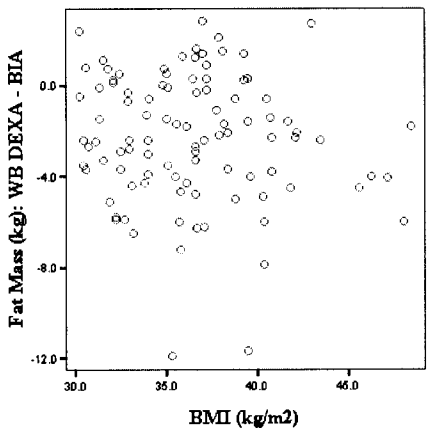
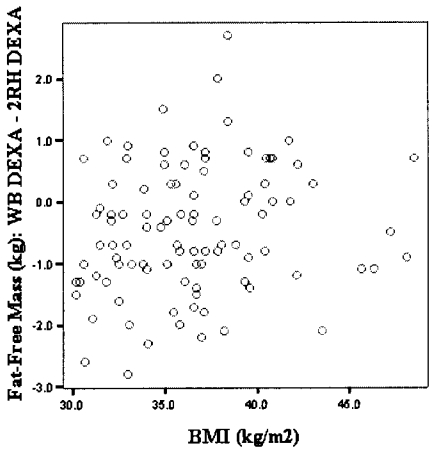


Figure 10. BMI versus difference in whole body DEXA scan analysis, half-body DEXA scan analyses, and BIA for each body composition parameters.









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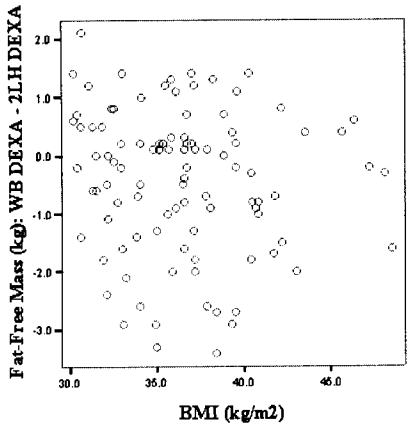
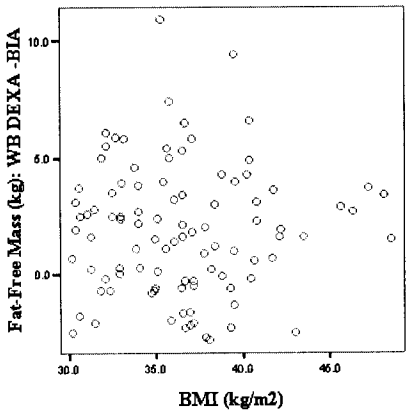
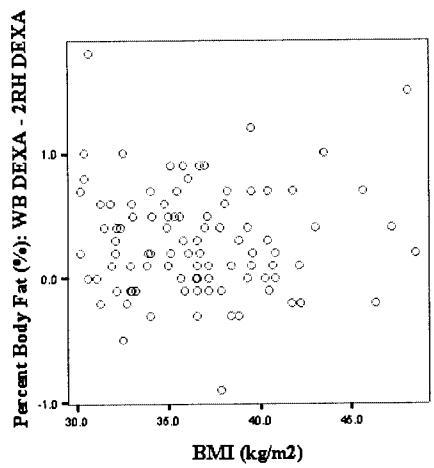
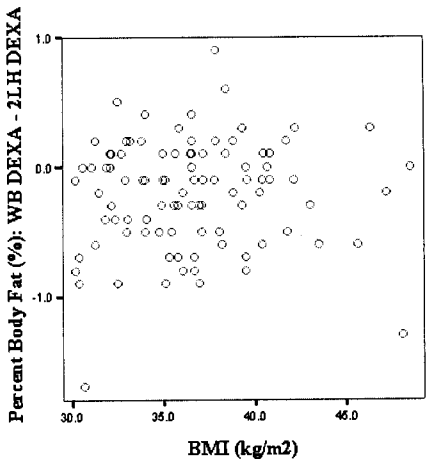
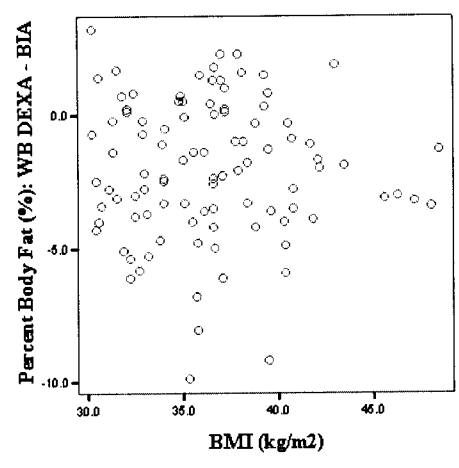










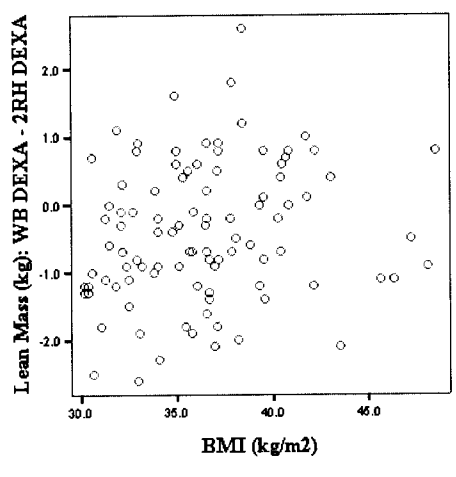


Figure 10. BMI versus difference in whole body DEXA scan analysis, half-body DEXA scan analyses, and BIA for each body composition parameter.

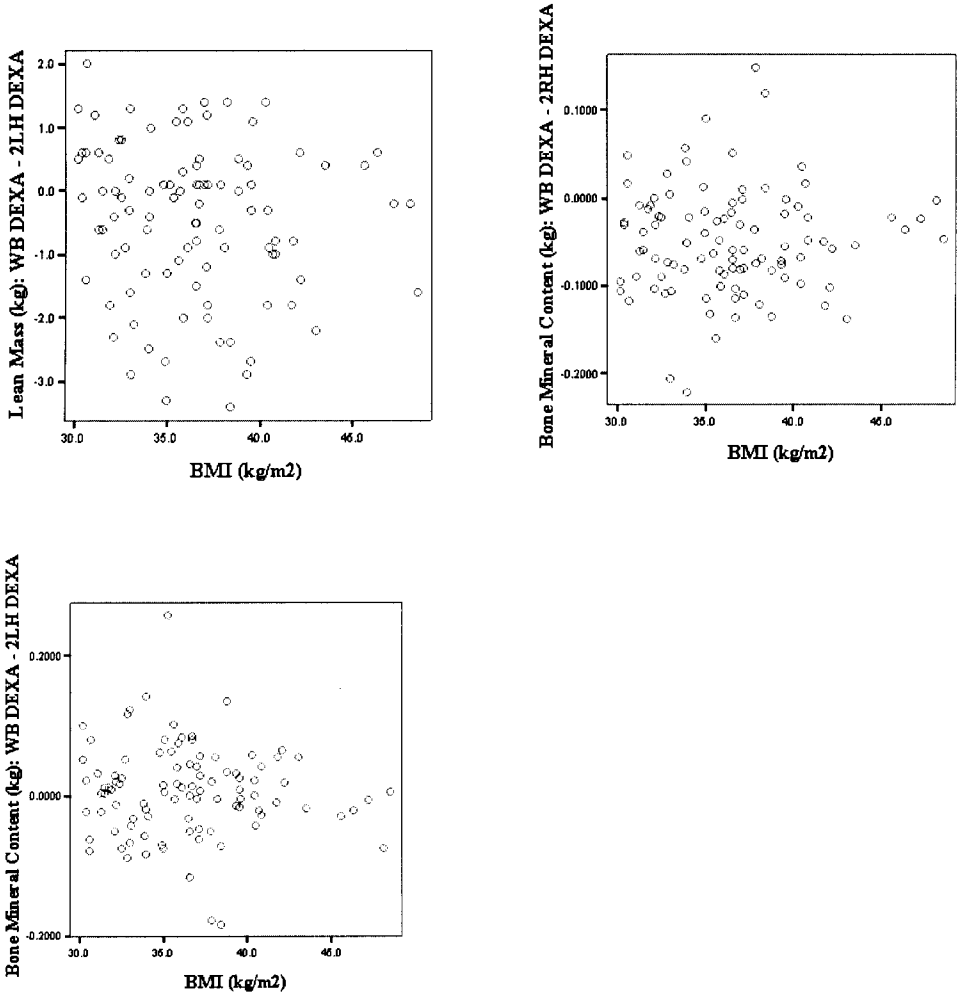
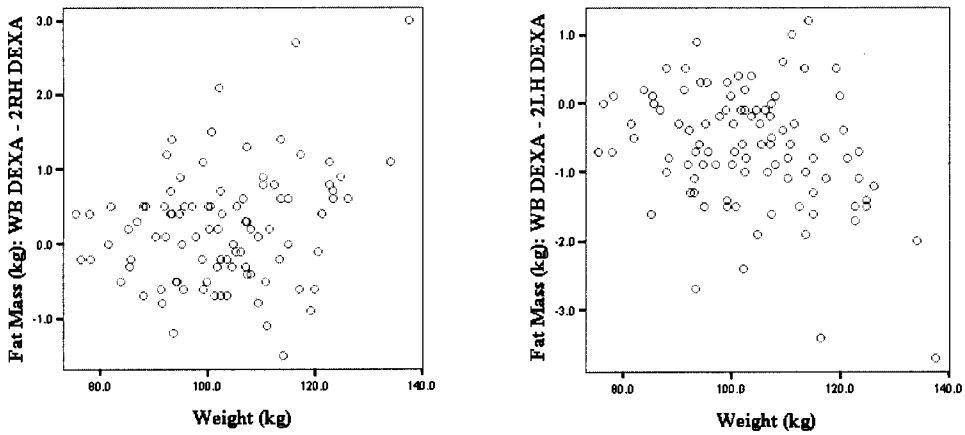


Figure 11. Weight versus difference in whole body DEXA scan analysis, half-body DEXA scan analyses, and BIA for each body composition parameter.



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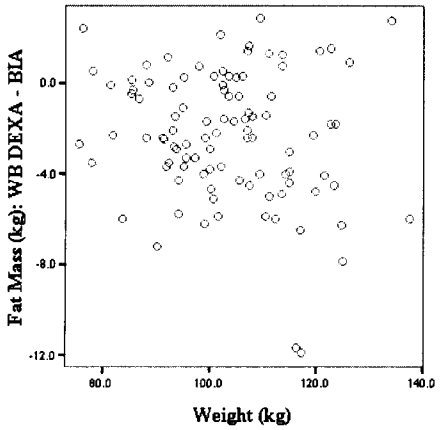

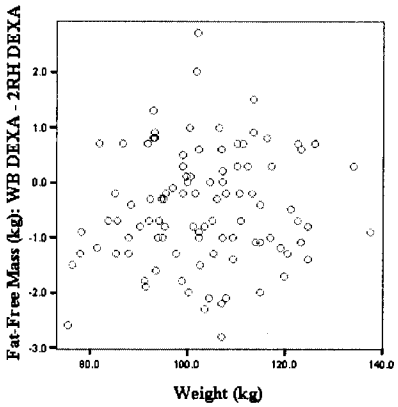

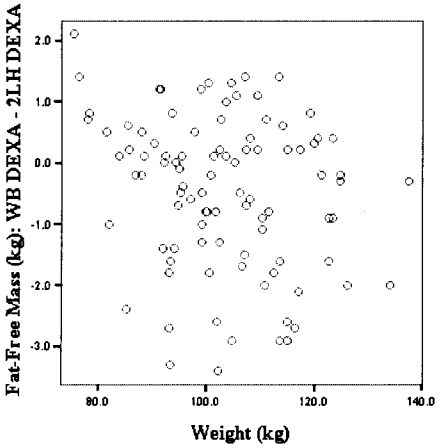

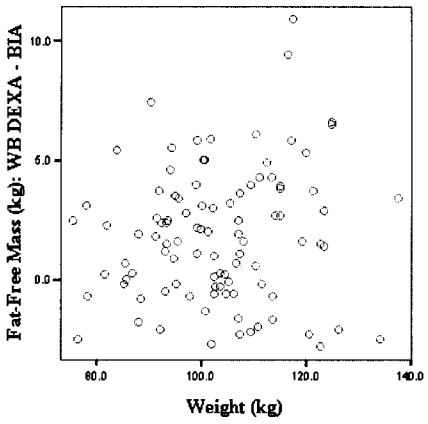

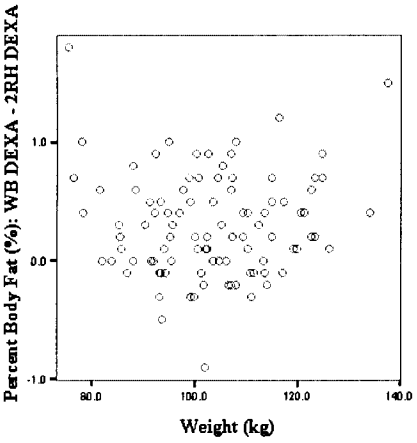

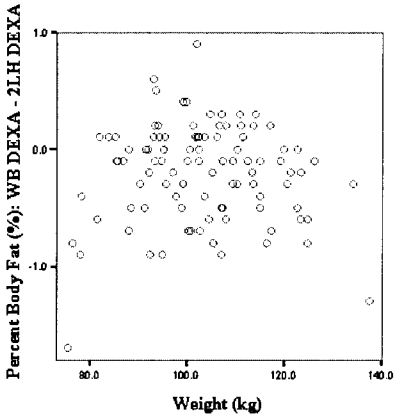

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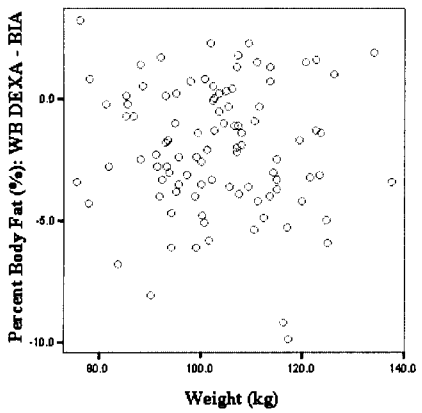
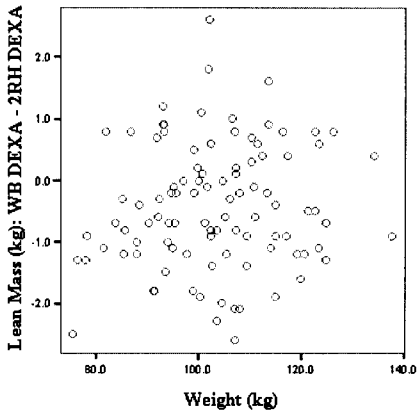
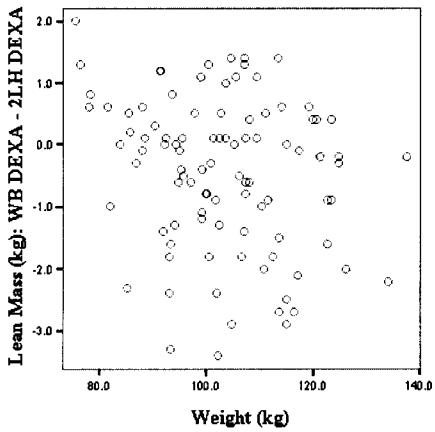
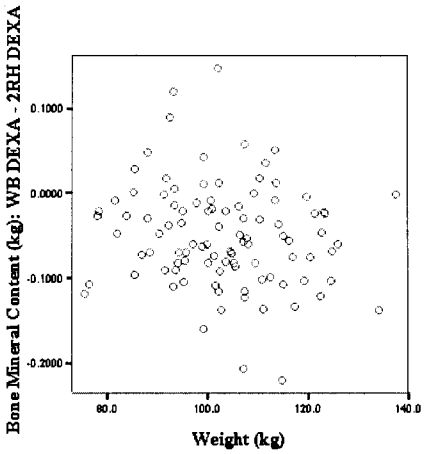








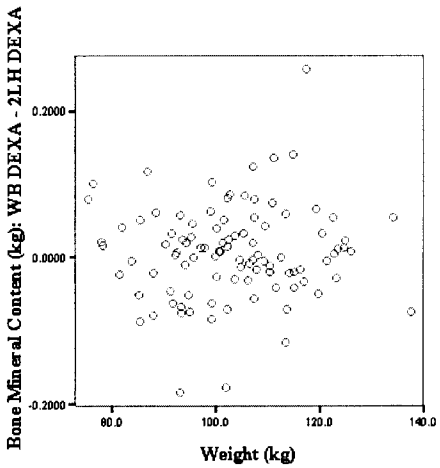
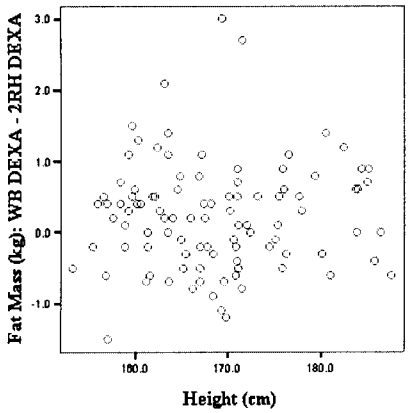
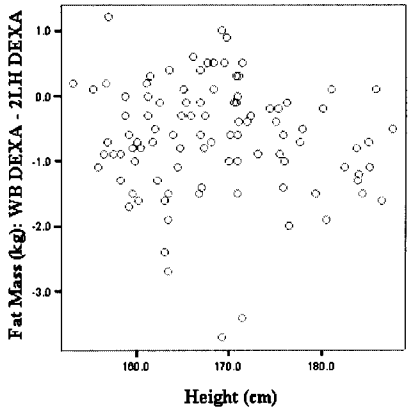
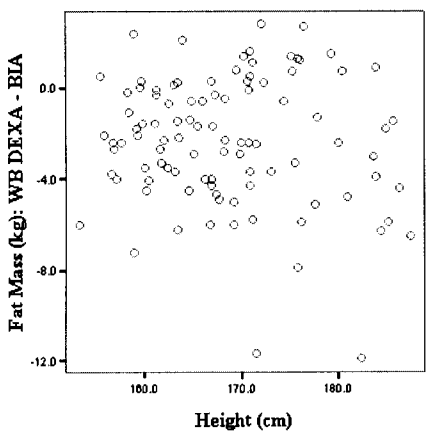
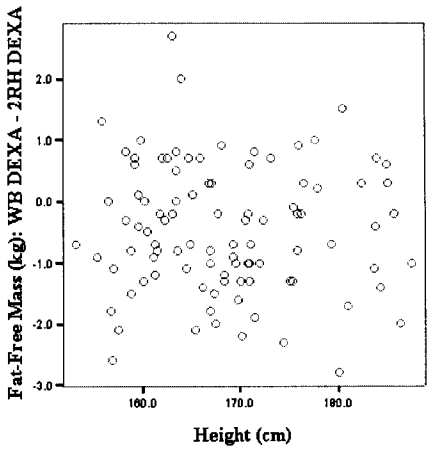


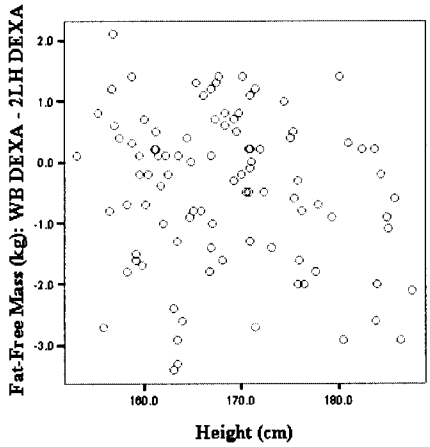
Figure 12. Height versus difference in whole body DEXA scan analysis, half-body DEXA scan analyses, and BIA for each body composition parameter.











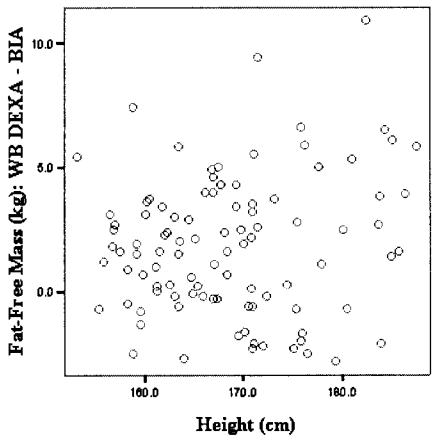
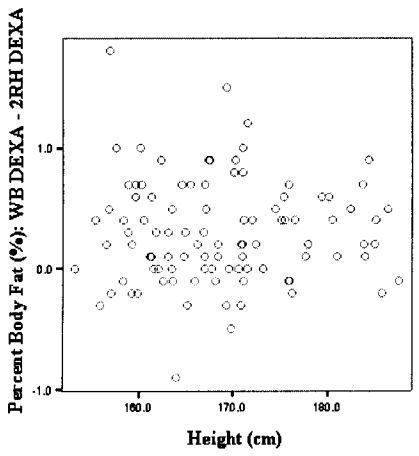
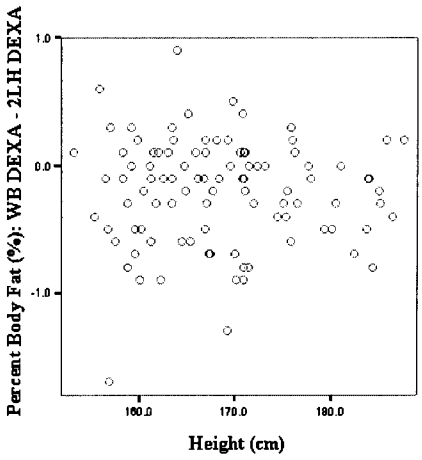
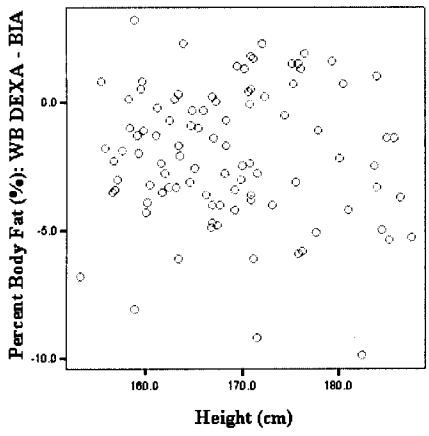
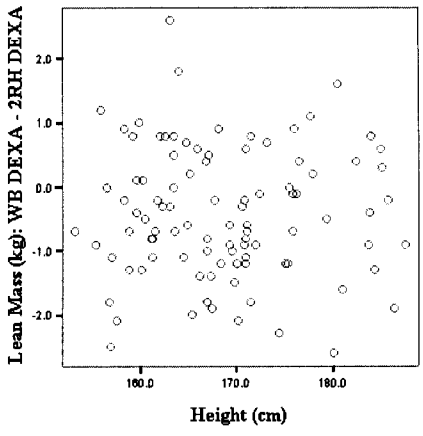


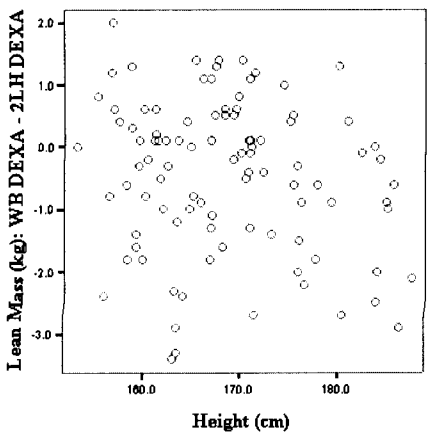
Figure 12. Height versus difference in whole body DEXA scan analysis, half-body DEXA scan analysis and BIA for each body composition parameter.











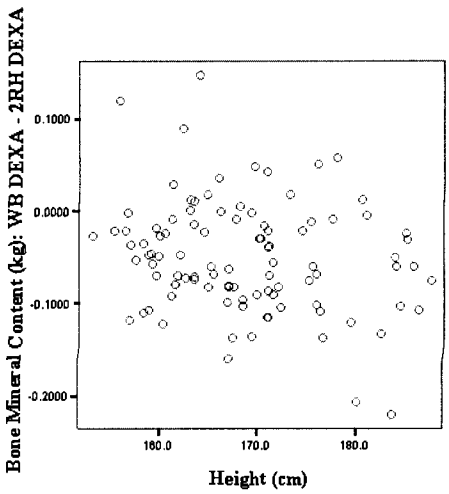
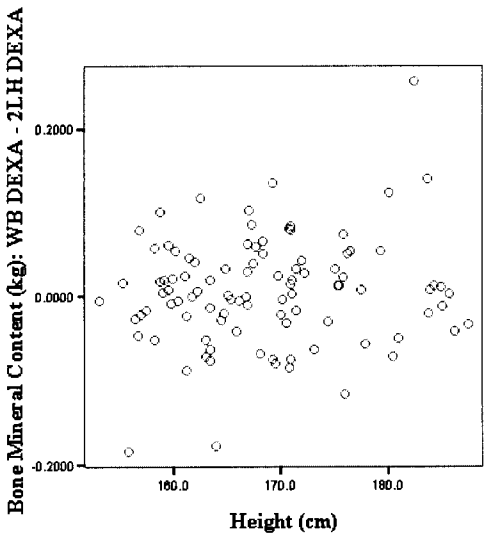


Figure 12. Height versus difference in whole body DEXA scan analysis, half-body DEXA scan analyses, and BIA for each body composition parameters.



APPENDIX E: SUBMITTED ABSTRACTS

Abstract Submitted 3/1/05 to General Clinical Research Center; Presented at Poster Session of Student Research Forum 5/12/05

Comparison of Body Composition Techniques in Obese Adults

Whitney Silverstein, Diane Stadler, Brad Scott, Dawn Peters; *Department of Medicine and General Clinical Research Center, Oregon Health and Science University* Portland, Oregon 97239

Accurate measurement of body composition is essential to assess the differential impact of weight loss interventions on lean, fat, and bone mass. Use of dual-energy X-ray absorptiometry (DEXA) to measure body composition of obese individuals is limited by body weight, body displacement, and trunk height. The purpose of the study is to compare traditional total body DEXA position and scan analysis with half body DEXA position and analysis, and to compare body composition analysis by DEXA, bioelectrical impedance analysis (BIA) and air displacement plethysmography. All measurements were performed in the OHSU GCRC Body Energy and Composition Core Lab by the same technician. Body composition was measured by whole body DEXA scans (Hologic Discovery Series Densitometer, Hologic, Inc., Bedford, MA), by BIA (Body Composition Analyzer, Model 310e, Biodynamics Corp., Seattle, WA) and by air displacement plethysmography (BOD-POD, Life Measurement, Inc. Concord, CA). Individual DEXA scans were analyzed 3 ways: traditional total body assessment and right and left half-body assessments. A sagittal line based on anatomical reference points (skull, spine, pelvis and legs) was positioned to distinguish left and right halves of the body scan. For analysis and comparison purposes, all parameters from the half body

assessments were multiplied by two. Two-tailed paired t-tests were used to determine significance of differences in fat mass, lean mass, and bone mineral content analyzed by DEXA total body scan analysis (Total), and two times the left-side (2LH) and two times the right-side (2RH) of the body analysis. Paired t-tests were used to determine significant differences between measurements by DEXA, BIA and BOD POD. Data from 15 subjects (11 female, 4 male) with valid measurements for all 3 assessments were included in the analysis. The participants studied were 41.3 ± 10.5 years old, weighed 101.1 ± 13.9 kg, were 167.8 ± 10.3cm tall and had a body mass index was 36.0 ± 5.1.

TABLE 1: Comparison of Body Composition Techniques in 15 obese adults

		Mean Difference	95% CI of Difference		p-value
Comparison of whole and half-body DEXA scans			Lower	Upper	
Fat Mass (kg):	**Total-2LH**	-0.71	-1.08	-0.34	<0.01
	Total-2RH	0.46	0.06	0.86	0.03
Lean Mass (kg):	**Total-2LH**	-0.74	-1.36	-0.12	0.02
	Total-2RH	-0.02	-0.65	0.61	0.95
Bone Mineral Content (kg):	**Total-2LH**	-0.01	-0.07	0.06	0.81
	Total-2RH	-0.03	-0.09	0.03	0.30
Comparison between techniques					
Fat Mass (kg):	**DEXA-BIA**	-0.85	-2.39	0.70	0.26
	DEXA-BOD POD	-5.36	-7.61	-3.11	<0.01
% Body Fat:	**DEXA-BIA**	-0.17	-1.7	1.36	0.81
	DEXA-BOD POD	-4.96	-6.87	-3.05	<0.01
Fat-Free Mass (kg):	**DEXA-BIA**	-0.75	-2.28	0.77	0.30
	DEXA-BOD POD	4.84	2.80	6.88	<0.01

The 95% CI suggests that the mean fat mass based on the left-half-body scans is between 0.34 and 1.08 greater than that for total-body scans and the right-half-body is between 0.056 to 0.864 kg less than that for total body scans. The difference in lean mass between total-body scan and the left-half-body scan were significantly different, with the left-half greater than total-body scans by 0.120 to 1.36 kg. The right-half was not significantly

different from the total-body analysis of lean mass. Total bone mineral content was not significantly different for either half-scan when compared to the total-body scan. Compared to total-body DEXA analysis, BOD POD analysis overestimates fat mass and percent body fat by 5.36 kg and 4.96%, respectively, and underestimates lean mass in obese individuals by 4.84 kg. Measurements of lean and fat mass by BIA and DEXA were not significantly different. Further analysis is needed to determine the accuracy of half-body DEXA measurements in obese individuals who meet weight criteria but do not fit within the DEXA scanning plane. In addition, anthropometric criteria to predict fit within the DEXA scanning area is needed to determine proper positioning of obese individuals before scanning takes place.

APPENDIX E: SUBMITTED ABSTRACTS

Abstract Submitted 11/2/05 to Experimental Biology 2006, presented April 2, 2006.

Whole and half-body dual-energy X-ray absorptiometry (DXA) analysis of body composition in obese adults

Whitney Silverstein[1], Diane Stadler[1], Dawn Peters[1], Jerome Differding[1], Njeri Karanja[2]

[1]Oregon Health & Science University, Portland, OR, [2]Kaiser Center for Health Research, Portland, OR

Whole body DXA (WB) scans require subjects to weigh less than the manufacturer's maximum weight limit and to fit completely within the scanning area. To accommodate subjects who meet the weight criteria but exceed the scanning area, alternative methods should be explored. This study compares WB DXA to half body DXA scans in 100 obese adults with an average weight of 103 ± 13 kg, an average BMI of 36 ± 4 kg/m^2, and who fit within the DXA scanning area. Left and right half-body DXA values were multiplied by two (2LH and 2RH) and differences from WB DXA were compared using paired t-tests.

Parameters	Comparison	Mean Difference	95% CI Lower	95% CI Upper	p-value
Fat Mass (kg)	WB-2LH	0.36	0.04	0.68	<0.05
	WB-2RH	-0.52	-0.82	-0.23	<0.01
Lean Mass (kg)	WB-2LH	1.86	0.47	3.25	<0.05
	WB-2RH	1.30	0.49	2.12	<0.05
Bone Mineral Content (BMC) (kg)	WB-2LH	-0.05	-0.06	-0.03	<0.01
	WB-2RH	0.01	-0.01	0.02	0.53
% Body Fat	WB-2LH	0.25	-0.02	0.51	0.07
	WB-2RH	-0.25	-0.53	0.03	0.08

Fat and lean mass are lower by the 2LH method compared to the WB method. Fat mass is higher, and lean mass is lower, by the 2RH method compared to the WB method. BMC is higher by the 2LH method, but not significantly different by the 2RH method compared to the WB method. Differences in body composition parameters measured by

half- and whole-body DXA analyses, although statistically different, are not clinically different. These results suggest that half-body DXA analysis is a reasonable alternative to WB DXA analysis to measure body composition when subjects meet the weight criteria but do not fit within the scanning area. Funded by grants 5 MO1 RR000334 and RO1 AT001930-01 A1.