ACCURACY IN BODY COMPOSITION ASSESSMENT WITH THREE DIFFERENT METHODS COMPARED TO DEXA

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ABSTRACT

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The purpose of this study was to investigate differences among the percent body fat (%BF) values of Turkish sedentary male and female university students measured by dual-energy x-ray absorptiometry (DEXA), skinfold (SKF), ultrasound (US) and hand to hand bioelectrical impedance analysis (BIA). Two hundred eight Turkish university students (one hundred four males and one hundred four females) aged between 18 to 26 years old participants participated in this study voluntarily. %BF assessment was performed by the SKF, US, BIA and DEXA methods. Differences among DEXA, SKF, US and BIA were examined by applying a series of paired-t test. Multiple regression analyses were conducted to developed regression equations to predict %BF from SKF and US measurements. Results demonstrated that there were significant differences between DEXA and SKF, US, and BIA measurements for males and females. The mean %BF derived from DEXA was significantly ($\underline{p}<.001$) greater than those of SKF, US and BIA for males and females. Multiple regression analyses showed that SKF and US measurement of subcutaneous fat at three-sites gave the best prediction to %BF for male and female separately. The multiple correlations using three sites simultaneously for men and women were r=0.92, SEE=2.4 and r=0.91, SEE=2.8 for SKF and r=0.93, SEE=2.3 and r=0.90, SEE=3.0 for US, respectively. In summary, with the new regression equation US appears to be a reliable, portable, and non-invasive tool which can be used by any field investigator on obese or thin individuals. Finally, new regression equations developed do not seem to be superior to those reported using calipers.

Keywords: Percent Body Fat, DEXA, Skinfold Thickness, Ultrasound, Hand-to-Hand BIA.

ÖZ

DEXA İLE KARŞILAŞTIRILDIĞINDA ÜÇ FARKLI YÖNTEMLE DEĞERLENDİREN VÜCUT KOMPOZİSYONUNDAKİ DOĞRULUK

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Bu çalışmanın amacı spor yapmayan Türk erkek ve bayan üniversite öğrencilerinin vücut yağ yüzdelerini (%BF) ölçen çift enerjili x ışını abzorbsiyometresi (DEXA), deri kıvrımı (SKF), ultrason (US) ve elden ele ölçüm yapan bioelektiriksel impedans analiz (BIA) yöntemleri arasındaki farkları incelemekti. Bu çalışmaya yaşları 18 ile 26 arasında değişen ikiyüz sekiz (yüz dört erkek ve yüz dört bayan) Türk üniversite öğrencisi gönüllü olarak katıldı. Yüzde vücut yağ değerlendirmeleri SKF, US, BIA ve DEXA metodlarıyla yapıldı. DEXA, SKF, US ve BIA arasındaki farklar erkekler ve bayanlar için ayrı ayrı uygulanan ilişkili örneklemler için t-testi ile incelendi. Çoklu regresyon analizleri SKF ve US ölçümlerinden vücut yağ yüzdesini tahmin eden regresyon denklemleri geliştirmek için uygulandı. Sonuçlar erkekler ve bayanlarda DEXA ile SKF, US ve BIA ölçümleri arasında anlamlı farklar olduğunu gösterdi. Erkeklerde ve bayanlarda DEXA'dan elde edilen ortalama vücut yağ yüzdesi SKF, US ve BIA'dan elde edilenden $p<.001$ düzeyinde anlamlı olarak daha büyüktü. Çoklu regresyon analizleri gösterdiki erkeklerde ve bayanlarda ayrı ayrı üç bölgeden alınan SKF ve US deri altı yağ ölçümleri vücut yağ yüzdesini en iyi tahmin etti. Üç bölgenin bir arada kullanıldığı çoklu korelasyonlar erkeklerde ve bayanlarda sırasıyla SKF için $r=0.92$, SEE=2.44 ve $r=0.91$, SEE=2.8 ve US için $r=0.93$, SEE=2.3 ve $r=0.90$, SEE=3.0'tü. Sonuç olarak yeni regresyon analiziyle US herhangi bir saha araştırmacısı tarafından güvenilir, taşınabilir ve invazif olmayan araç olarak kullanılabilir gibi görünüyor. Ayrıca yeni geliştirilen US regresyon denklemleri kaliper kullanılarak geliştirilen denklemlerden üstünmüş gibi gözükmüyor.

Anahtar kelimeler: Vücut Yağ Yüzdesi, DEXA, Deri Kıvrımı Kalınlığı, Ultrason , Elden Ele Ölçüm Yapan BIA.

To My Parents

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Date: 29.08.2003 Signature:

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LIST OF ABBREVIATIONS

BF	Body Fat
%BF	Percent Body Fat
FM	Fat Mass
FFM	Fat Free Mass
LBM	Lean Body Mass
BMI	Body Mass Index
UWW	Under Water Weighing
BIA	Bioelectrical Impedance Analysis
SKF	Skinfold
US	Ultrasound
DEXA	Dual-energy x-ray absorptiometry
BMC	Bone Mineral Content
BMD	Bone Mineral Density

CHAPTER 1

INTRODUCTION

Body composition is a health-related component of fitness. It is important for professionals to have a general understanding of the most commonly used techniques for assessing body composition. Measurement of body composition has become a popular and standard practice for physicians, athletic trainers and allied health professionals. An accurate assessment of body composition is necessary to properly identify an excessive low or high relative body fat . This assessment can then be used to estimate a subjects' ideal body weight and formulate an exercise and diet regimen.

Body composition refers to the body's chemical composition. The body may be regarded as being composed basically body fat (BF) and fat-free mass (FFM) or lean body mass (LBM). The amount of BF (adipose tissue) that is stored is determined by two factors: (1) the number of fat-storing cells or adipocytes; and (2) the size or capacity of the adipocytes (Fox, 1984).

Fat tissue in the human body can be subdivided into essential and storage fat. Essential fat is located in bone marrow, heart, lungs, gall bladder, kidneys, large and small intestines, nerve tissue, muscles and various organs. Essential fats are necessary for physiological functions and it reflects the gender dependent characteristics in females. The higher percentage of essential fat in females is related to the protection of reproductive organs. Therefore the percentage of total body fat for a reference man and woman is 15% and 27%, respectively (McArdle, Katch, and Katch, 1981).

Storage fat, as its name implies, is stored as an energy reserve in adipose tissue. Essentially, the amount of storage fat does not differ between the sexes; however, essential fat is four times greater in females. It is considered that this difference results from birth and sexuality hormones (McArdle, Katch, and Katch, 1981). Storage fat can be further categorized as brown and white adipose tissue. Both tissues use the same metabolic pathways (for example, for fatty acid storage and release) and are histologically similar in the newborn infant. The difference in these tissues concerns function. Brown tissue is used for the generation of heat (thermogenesis) while white adipose tissue serves as a substrate for energy metabolism. In man, until 10 years of age, brown adipose tissue is widely distributed throughout the body (Leibel, Berry, and Hirsch, 1983). In subsequent years brown tissue disappears, presumably taking on the morphological characteristics of white tissue (Nobel, 1986).

When the weight of body fat is subtracted from the total body weight, the remaining weight is referred to as FFM or LBM. The FFM reflects mainly the skeletal muscle mass but also includes the weight of other tissues and organs such as bone and skin. The muscle mass makes up about 40 to 50% of the FFM. The fewer the amounts are BF, the more the FFM will be. The average FFM of college-aged men is about 85% of their total body weight, and that of college-aged women about 75% of their total body weight (Fox, 1984).

Reference model of body composition suggested by Behnke (1968) is quite useful to understand and compare the content of body composition more easily. Theoretical model that is suggested is obtained from anthropometric measurement of American subjects. Body composition of a reference person is presented in Figure 1.

	Male	Female
Age (year)	20-24	20-24
Height (cm)	174	163.8
Weight (kg)	70	56.8
Total fat (%)	15	27
Storage fat (%)	12	15
Essential fat (%)	3	12
Muscle (%)	44.8	36
Bone (%)	14.9	12
Remainder (%)	25.3	25

Figure 1. Body composition of reference person according to the theoretical model of Behnke.

Body weight alone does not provide enough information about body composition. The term overweight refers to an amount of total body weight (mass) above what is recommended based upon stature (Brozek & Henschel, 1961). The Metropolitan Life Insurance tables for height and weight have been used for years as a standard index for health professionals to determine appropriate body weight (Harrison, 1985). More recently, the body mass index (BMI), which is the ratio of weight to height squared ($BMI = wt/ht^2$ expressed as kg/m^2), became more popular for use in epidemiological research (Millar& Stephens, 1987; Keys et al., 1972). The problem with the term overweight and use of height-weight or BMI measures is their lack of specificity in describing leanness-fatness. Thus, the term obesity is used to depict specifically what proportion of the body composition is fat (i.e., being too faty) (Powers & Howley, 1997). Wilmore and Haskell (1972) demonstrated the problem with using the term over-weight to describe body composition (leanness-fatness). One may weight much more than the average weight for height standards based on insurance company statistics, yet still be not obese in terms of the body's total quantity of fat. The extra weight could simply be additional muscular mass (Mcardle, 1982).

Periodic body composition measurements can be used to assess the effectiveness of exercise and diet interventions or monitor changes in body compositions associated with growth and maturation or disease states (Wagner& Heyward, 1999; Maud & Foster, 1995). Evidence supports the notion that being overweight (excess body fat) is related to musculoskeletal injury, non-adherence to exercise training and reduced athletic performance (Cureton et al., 1978; Bray, 1985). Body composition has also been linked to numerous health conditions, such as cardiovascular disease (Rexrode et.al., 1996; Gunnell et al., 1998), hypertension (Wada & Ikeda, 1998), diabetes mellitus (Knowler et al., 1993; Hanson et al., 1995; Fujimoto, 1996), hyperlipidemia (Despres et al., 1990), gallbladder disease (Diehl, 1991; Misciagna et al., 1996; Chapman et al., 1996), certain types of cancers (Garfinkel, 1985), osteoporosis, osteoarthritis (Maud & Foster, 1995) and it is also associated with increased mortality (Seidell et al., 1996; Singh & Lindsted, 1998; Dongsheng et al., 2000). In a 26-year follow-up of participants from the Framingham Heart Study, Hubert, Feinlab, McNamara, & Castelli (Hubert et al., 1983) showed that obesity itself is an independent risk factor for mortality from cardiovascular heart diseases. Thus, there is a clinical need to measure not only %BF but also fat distribution, muscle mass and bone mass as well. Whatever the reason for assessing body composition, health and physical educators, fitness specialists, nutritionists and other clinicians in health-related fields should have a general understanding of the most commonly used techniques for assessing body composition (Wagner & Heyvard, 1999).

In spite of numerous methods, measuring body composition is challenging and, depending on the chosen technique, requires sophisticated and expensive instrumentation (Lukaski, 1987). However, all improved methods used to determine the degree of fatness presents some difficulties in different points, such as lack of accuracy, generalizability, need for sophisticated instruments and skilled technicians (Wagner& Heyvard, 1999).

Body composition assessment can be done by laboratory or field methods. Laboratory methods for assessing body composition involves chemical analysis of cadavers, underwater weighing (UWW), volumetry, helium dilution, radiographic (X-ray) analysis, ^{40}K counting (radiation emission), total body water, ultrasound, bioelectrical impedance (BIA), total body electrical conductivity, and infrared interactance measurements. Field methods for body composition assessment include anthropometry (skinfolds (SKF) and girths), the body mass index (BMI), height-weight tables and the waist-hip ratio (Morrow, Jackson, Disch, & Mood, 2000).

Body composition evaluation is generally directed to assess two compartments, FM and FFM (Keys &, Brozek, 1953; Brozek et al., 1963; Siri, 1961; Brozek & Henschel, 1961). The FFM includes muscle, bone and other non-fatty tissues (Figure 2). Accordingly, to evaluate body composition there is a need of a technique that is safe, noninvasive, rapid an at the same time reliable, accurate, sensitive and repeatable to the small differences that may occur over the course of physical training and/or dieting **(**Maud & Foster 1995, Lohman, 1986).

Several methods of estimating these two compartments are used in research studies. Among these methods, UWW is probably the most widespread technique used as reference method to estimate FM (Lohman, 1981).

Although the two-compartment model is well accepted and used extensively in research and clinical settings, it's not without problems. This system assumes that the composition of fat and FFM is constant for all individuals, that is, that the density of fat is 0.900 g/cc and FFM is 1.100 g/cc. (Siri, 1961; Brozek et al., 1963). Clarys, Martin, and Drinkwater (1984) studied dissection data from 25 cadavers and found a considerable variation among subjects in density for bone and muscle.

The variation in FFM composition in this specific population was approximated at 0.006 g/cc by Lohman (1981), which could cause an error of 2.5% in estimated percent fat. Lohman (1986) has summarized the views of other investigators concerning two- to four-compartment systems used for body composition determination (Figure 2).

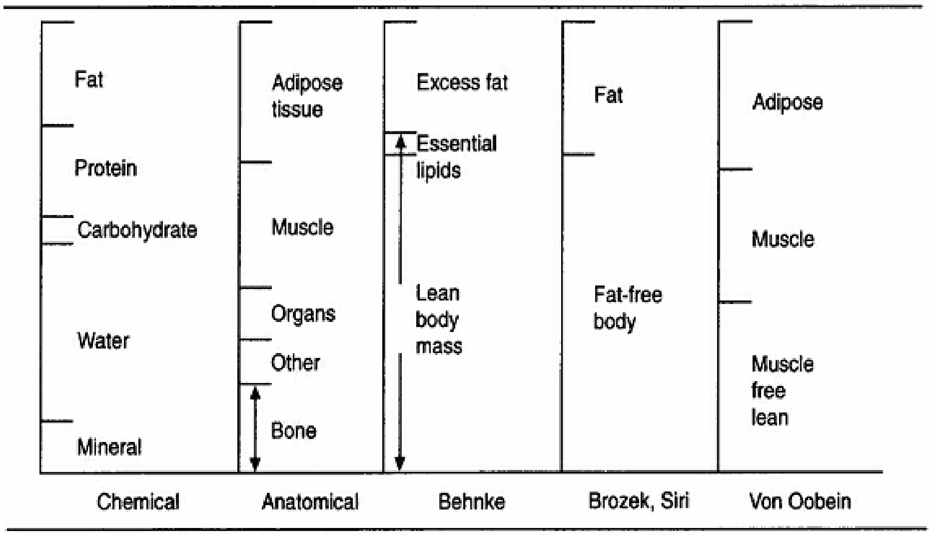

Figure 2. Models for determination of body composition by different investigators, from Lohman (1986).

Use of UWW as a gold standard method is limited because the relative water and bone mineral content of the FFM may differ from one person to the other. Moreover, shape of the water tank, temperature and purity of the water increases the measurement error results from UWW (Lohman, 1984; Modlesky et al., 1996).

The skinfold (SKF) thickness measurement is the most commonly used indirect method to estimate body density (Db) and then %FM (Lohman, 1981). Due to its relative low cost, simplicity and field applicable, the measurement of SKF is a popular method of estimating Db by several investigators (Behnke & Wilmore, 1974; Durnin & Womersley, 1974; Jackson, Pollock & Ward, 1980; Katch & Mcardle, 1975; Katch &. Michael**,** 1968; Lohman, 1981). The SKF technique involves pinching the skin with the thumb and forefinger, pulling it away from the body slightly, and placing the calipers on the fold. Thus, SKF measures the thickness of two layers of skin and the underlying subcutaneous fat (Adams, 1998). To standardize SKF measurements, guidelines for the anatomical location of SKF sites and measurement technique have been published (Harrison et al., 1988; Heyvard & Stolarczyk, 1996).

SKF measurements provide good estimates of body fat (Deurenberg & Deurenberg-Yap, 2002), but the observer needs to be skilled to obtain reliable mesurements (Sinning, 1980; Lohman, 1981). Brozek and Keys published the first valid SKF equations in 1951. Since that time, more than 100 prediction equations using various combinations of anthropometric variables have been reported in the literature (Durnin & Womersley, 1974; Jackson & Pollock**,** 1978; Katch & Katch**,** 1980; Lohman, 1981). While most studies show that SKF can account for 50-70 % of the variance in body density within a given sample, many factors have been found to influence the results and to limit the usefulness of applying an equation derived from one sample to another. The various factors limiting the general use of the regression equations were reviewed by Katch & Katch (1980), Lohman (1981) and Sinning (1980).

Some authors have shown that 1) different prediction equation results from different populations, 2) important sources of variability results from the different methods of measuring body density to predict body fat, and 3) there is variability in the way different investigators measure SKF. The type of SKF caliper may also be an important factor because of the variability in design and use of various instruments now available; however, this aspect has received limited attention (Burkinshaw, Jones & Krupowicz, 1973; Sloan & Shapiro, 1972; Womersley & Durnin, 1973).

Within the last several years there has been increased interest for the use of hand-held BIA technique to obtain information on body composition. The measurement is rapid, easy to use, and non-invasive, relatively inexpensive and suitable for epidemiological investigations on population groups and for field studies (Lukaski et al., 1985; Jebb & Elia**,** 1993; De Lorenzo et al**.,** 1998).

Technically, in the BIA measurements, a small alternating current is passed through the body and its conductance is measured. The conductance is mainly determined by the amount of the water in the body, which is only present in the fat-free mass. Impedance measurements therefore allow assessment of the fat-free mass, and, by difference with body weight, assessment of body fat percentage (NIH Technology, 1994; Deurenberg, & Deurenberg-Yap**,** 2002). The classical total body BIA methods measures impedance from foot to hand and it requires placement of electrodes on well-defined landmarks on the body. This procedure takes time and may not be tolerated by subjects (Lukaski et al., 1985). Earlier studies (Fuller & Elia, 1989; Baumgartner, Chomlea & Roche, 1989) have shown that segmental impedance measurements (measuring defined parts of the body, such as the legs or the arms) also provide an assessment of body composition. Based on these observations, impedance analyzers have developed instruments to measure segmental impedance. Instrumentation is commercially available in which impedance of the arms (from hand to hand) and software in the instrument allows assessment of body fat percentage (Loy et al., 1998), using weight, height, age and sex as additional parameters.

Although its simplicity in usage, its accuracy decreases whenever the subjects are over or underhydrated, after any physical activity and water intake before the measurement. Even smoking can affect the results. Moreover, BIA measurements should be made in the same hour of day (Khaled et al., 1988).

In addition to high accuracy and portability, ultrasonic (US) measurements as a laboratory method have been used to assess muscle, bone and fat cross-sectional areas and to estimate total body composition (Lohman, 1984). The relation between whole-body composition and segmental cross-sectional areas has not been well investigated in humans. Thus, it has been extensively used in animal science. With the development of improved ultrasonic and radiographic techniques, excellent cross-sectional analysis of fat, muscle and bone distribution can be obtained (Borkan & Hults, 1983).

US measurement of tissue thickness has shown great potential as a method of assessment when compared to other methods such as skinfold, needle puncture and soft tissue roentgenogram (Quaade, 1956; Bullen et al., 1965; Booth, Goddard &

Paton, 1966; Haymes et al., 1976; Fanelli et al., 1984; Volz & Ostrove, 1984).

In recent years, dual-energy X-ray absorptiometry (DEXA) has been introduced as the gold standard to evaluate body composition (Bolanowski & Nilsson**,** 2001; Ogle et al., 1995; Svendson et al., 1993). DEXA has the potential to provide a more accurate assessment of body composition across populations than does hydrodensitometry and therefore it should be considered as the reference method (Friedl et al, 1992; Fuller et al., 1992; Prior et al., 1997).

DEXA, unlike other methods, measures three-components of body composition -FM, soft fat-free mass (FFM), and bone mineral content (BMC)- as well as regional fat distribution. This three-compartment model is based on the differential attenuation by body tissues of transmitted photons at two energy levels **(**Kiebzak et al., 2000; Slosman et al., 1992; Mazess et al., 1989; Svendson et al. 1991; Haarbo et al., 1991). DEXA measurements are not affected by race, athletic status or musculoskeletal development (Aloia et al., 1999; Prior et al., 1997). DEXA requires minimal cooperation from the participant. This method is relatively quick (most scans are completed within 20 min), precise and accurate for the measurement of body composition (Prior et al., 1997; Andreoli et al., 2002).

The greatest advantage of DEXA over other laboratory methods is its ability to assess regional as well as total body composition and analyze separate compartments of the body (fat, soft tissue and bone). (Svendson et al., 1993; Jensen.et al., 1993)

There are relatively few studies comparing the effectiveness of field and laboratory methods for body composition measurements in young (18-26 years of age) males and females. US measurements were compared with SKF measurements in only a few studies (Booth et al., 1966; Bullen et al., 1965; Fanelli et al., 1984; Volz & Ostrove, 1984) and the number of participants in that study was limited. Comparison of SKF, US, BIA and DEXA measurements was not conducted so far.

1.1. Hypothesis

1. There will be significant differences between the SKF and US measurements of subcutaneous fat at specified anatomical sites.

2. There will be correlations among the percent body fat values of sedentary male and female university students measured by DEXA and SKF, US and BIA.

3. The correlation between US and DEXA measurement will be higher than that of SKF and DEXA, and BIA and DEXA.

4. There will be significant differences among percent body fat values of sedentary male and female university students measured by DEXA, SKF, US and BIA.

1.2. Purpose of the study

US can be used as a field method for measuring body fat as accurate as laboratory methods in sedentary young university students. This study is designed to compare estimation of the %BF obtained from the SKF, US and BIA with DEXA, that is used as the reference method.

Therefore, The purposes of this study were;

1. To establish a standard of body composition for the measured age group of sedentary male and female university students using DEXA.

2. To compare the field applicable body composition measurement methods (SKF, US, BIA) with the laboratory methods (DEXA).

3. To correlate SKF and US measurements of subcutaneous fat with percent body fat obtained by DEXA.

4. To determine the validity and feasibility of US in body composition assessment as a field method.

5. To develop new regression equations to predict % BF from SKF and US measurements of subcutaneous fat using DEXA as a reference method.

1.3. Limitations

1. All participants were Middle East Technical University students.
2. Subjects were 18-26 years old.
3. All subjects were volunteers.
4. DEXA was the only method used as criterion to determine the body density and percent body fat for developing the regression equations.

1.4. Assumptions

1. All anthropometric SKF, BIA, US and DEXA measurements performed were valid and reliable.

2. The instruments used were accurate and calibrated. The medical center at which the measurements were obtained has the ISO 9001: 2000 certificate and all instruments are regularly calibrated by the TSE (Turkish Standard Institute).

3. The subjects followed and performed all pre-test instructions properly.

1.5. Significance of the study

Because of height-weight tables and BMI's failure to predict fatness, measurement of body composition, i.e. determination of fat free mass and fat mass, has become an important point of interest over the past years. Body fat and fat free mass were considered to be the two main body components building up the body composition. Therefore, several methods have been developed.

Today, there are two methods 1) Direct and 2) Indirect measurements in determination of body composition. Direct measurements include chemical determination of soft tissue from the animal and human cadavers. On the other hand, indirect measurements are UWW, SKF, chemical analyses, fat soluble gaseous uptake, secretion of creatine, 3-methlyhistidine, total body potassium counting, magnetic resonance, BIA, US, DEXA and less-known others (Morrow, Jackson, Disch, & Mood, 2000).

Direct methods, which are theoretically the most valid, are used to test the validity of the indirect methods. Because of their usability, indirect methods are used extensively in sedentary and sportsmen. Most of the indirect methods are generally used in the laboratory conditions than in the field. The most well known method used to determine body composition is UWW and SKF. Although Simple measurements such as, body circumferences, diameters, BIA, SKFs for prediction of the fat percentage are easy to performed, portable, field applicable, fast and cheap; they have proven to be highly population specific, having large prediction errors, lack of accuracy and reproducibility.

On the other hand UWW method is a relatively accurate method but has some limitations too. It needs both experienced operator and subject's cooperation.

However, some people feel uncomfortable when they must be fully submerged, leading to incorrect reading. Moreover, it is difficult accurately correct the air left in the lungs and it does not take into account the location of body fat (Fiedl, 1992). However UWW was used as reference for a long time in literature.

UWW is replaced with DEXA, which is accepted as the gold standard recently. The latest body composition method research uses DEXA predetermine body fat distribution. Its results have been reported to be accurate and precise in comparison with in vivo or in vitro multiple component reference method (Erselcen, 2000). Because of less time consuming, it allows both total body and regional analyses, precise, accurate, reliable, safe, causes a minimal radiation dose, and non-invasive method with only few limitation (Bolanowski and Nilsson, 2001). It is used only in laboratory settings and its equipment is quite expensive. Also narrow table limits its usage with heavier people.

Although there are some studies (Açıkada, 1990; Doğu, 1984; Zorba, E. 1984; Kutlu, 1991; Zorba, 1989) about body composition in Turkey, they have been realized on the prepubescent, junior, senior or elite Turkish wrestlers or athletes. Thus, there are a few studies on sedentary Turkish people in the literature (Doğu, 1984; Zorba, 1986; Ertat, Akgün and Aksu, 1988). Researches performed on sedentary Turkish people have limitations such as, small number of subjects and measuring only one gender. Additionally, UWW had been used as the only reference method in all of the researches performed in Turkey. In all of the studies, actual residual volume of subjects was not measured but estimated. The most important aspect of this study is the use of DEXA as a reference method. Comparison of SKF, US, BIA and DEXA measurements was not conducted so far.

Percent fat estimation of young adults obtained from SKF, US, and BIA should be compared with DEXA. Furthermore, regression equations should be developed to predict percent body fat from anthropometric measurements of SKF and US using DEXA as the reference method.

1.6. Definition of Terms

Overweight : Weight in excess of normal range. It is identified as body fat in excess of 25%-30% for men and 30%-35% for women (Lohman, 1982).

Obesity : An excessive amount of total body fat for a given body weight. It is identified as body fat in excess of 30% for men and 35% for women (Lohman, 1982).

Percent body fat (%BF) : Referred to as relative body fat, which is obtained by dividing the fat mass by the total body weight (Lohman, 1982).

1.7. Equipment Used

1. Holtain Skinfold Caliper: This instrument has been designed to give a constant pressure of 10 g/mm^2 over its entire operating range. Its gag marked into division of 0.2 mm but reading of 0.1 mm can be easily estimated (see figure 3).

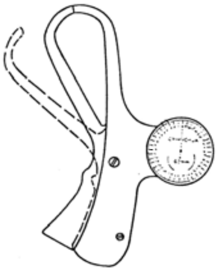

Figure 3. Holtain Skinfold Caliper.

2. Ultrasound: Sound waves are transmitted through tissues and the echoes are received and analyzed. This technique has been used to measure the thickness of subcutaneous fat (see Figure 4).

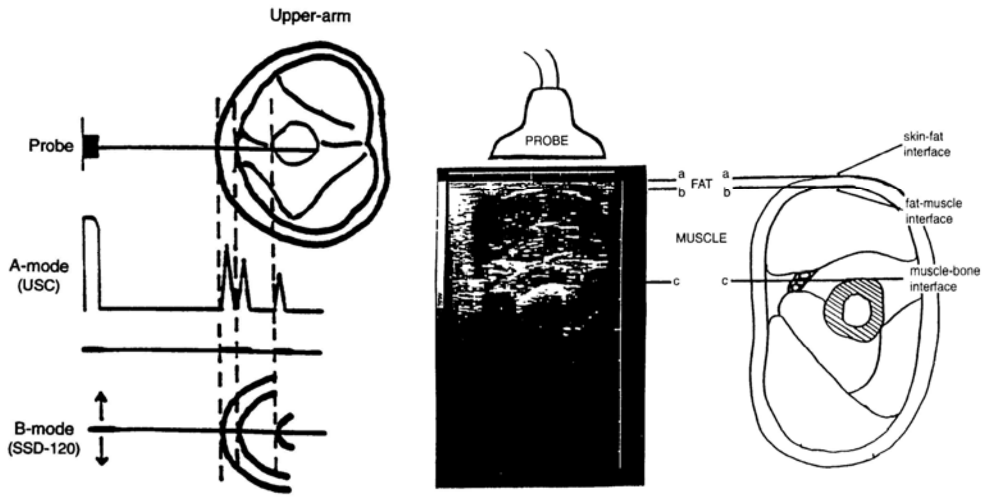

Figure 4. Ultrasound imaging

3. Hand-to-Hand Bioelectrical Impedance : The measurement of percent body fat was taken by the Omron BF 300 body fat monitor. An electrical current (50 µA usually set a frequency of 50 Hz) is applied to an extremity and resistance to that current (due to the specific resistivity and volume of the conductor- the fat-free mass) is measured (see Figue 5).

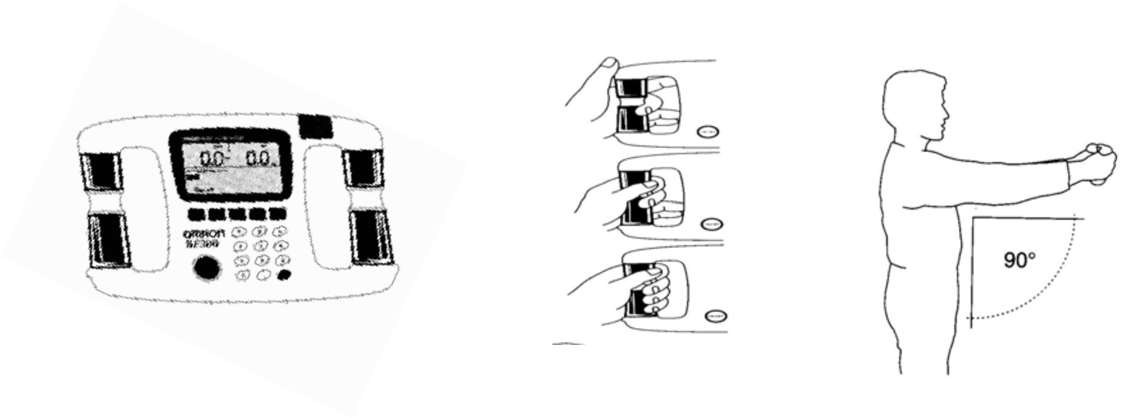

Figure 5. Hand-to-hand Bioelectrical impedance

4. Dual Energy X-ray Absorptiometer: DEXA uses a constant potential x-ray source and a K-edge filter (cerium) to generate two main energy peaks (40 keV and 70 keV). When the participant is lying supine on a padded table, an x-ray beam passes in a posterior to anterior direction through the bone and soft tissue upward to a detector. The ratio of x-ray beam attenuation at the lower energy relative to that at the higher energy is used to distinguish fat from the FFM (see Figure 6).

Figure 6. Dual energy-x-ray absorpiometer.

CHAPTER 2

REVIEW OF LITERATURE

Although the organs and systems in the human body have shown similarities, everybody is different in terms of physical characteristics. Various body types have been described as obese, thin, weak, long and short by people and their relationship with health, power, durability, agility, etc. has been investigated for a long time. Scientifically, it is accepted that the first study about surface area of human body started with mathematical computation of body surface area by Abernathy in 1793 (Cox, 1980).

There is evidence that research and interest in body composition was explored centuries ago by Archimedes, though most of the research data that is available on human body composition has been completed in the last forty years. With the recent interest in personal health, nutritional status and fitness, several methods of estimating body fat have been developed and used in clinical settings. Actually, the importance and development of body composition studies has gained speed after the symposium about anthropometric measurements organized in Illinois in 1963 (Lohman1984).

The assessment of body composition involves using the most appropriate, and accessible method possible to estimate a person's body composition (an actual assessment of body composition would be by cadaver analysis). The accurate measurement of LBM or FM is now the most rational basis for nutritional and exercise prescriptions. Therefore, the importance of clinical body composition is now being recognized well. But, there is no direct way to measure the amount of fat in the human body, but there are a few indirect methods such as UWW, body circumference, and SKF measurements (Morrow, Jackson, Disch, & Mood, 2000).

One prevalent system of body composition assessment is the two-compartment model introduced by Brozek, Grande, Anderson, & Keys (1963) and Siri (1961), which assume the body is made up of fat and fat-free compartments. The terms fat-free mass and lean body mass are often incorrectly used interchangeably. Fat-free mass contains no lipids whereas lean body mass includes approximately 2% to 3% and 5% to 8%, for men and women, respectively (Heyward & Stolarczyk, 1996).

Lohman (1982) recommended a range of 10%-20% as an optimal health and fitness goal for males. He indicated that this range allowed for individual differences in physical activity and preferences, and was associated with little or no health risk due to diseases associated with fatness. Values above 20% increased the risk of diabetes, heart disease, and hypertension. Values of 20%-25% were considered moderately high, 25%-31% as high, and >31% as very high. Females were generally about 3% fatter than males prior to puberty and 11% fatter after puberty. The optimal range of body fat for adult females was 15%-25%, with 25%-30% listed as moderately high, 30%-35% as high, and >35% as very high.

Lohman also provided values for % body fat that were below the optimal range: for boys, 6% to 10% was classified as low and <6% as very low; comparable values for girls were 12% to 15% and <12%, respectively (Lohman, 1982).

Several investigations had utilized anthropometric techniques and indirect measurements of body fatness and fat-free weight. Two of the earliest studies were those of the Welham and Behnke, and Buskirk. A portion of the results from the latter study was published by Buskirk and Taylor, who presented body composition data from sedentary collage students, wrestlers, football players and gymnasts (Buskirk, 1984).

According to Wagner and Heyward (1999) football players were shown to be overweight according to the BMI, but when body composition was determined by hydrostatic weighing they were not considered over fat; they were overweight as a result of having excessive amounts of fat-free mass (FFM), not fat weight. For these reasons, numerous tools and methods have been developed to measure various body composition parameters that differentiate fat from FFM.

Ideally, the description of the body configuration and composition was best accomplished through the post mortem analysis and findings them correlated with the previously collected measurements on the living person. Mitchell et al. in 1945 and Forbes et al. in 1956 provided much of the classical cadaver description of the gross composition and chemical constituent of the human. Other studies of body composition by direct body cadaver dissection were completed by Pitts in 1963 and Dempster and Gaughran in 1965. The latter was a description of eight male cadavers establishing approximate standards for the weight, volume, and density of the different body segments and should be of interest to kinesiologist (Doğu, 1984).

Since direct chemical analysis of the whole body or part of it is not possible with the living subjects, other methods have been developed. The use of body density derived from UWW as the determination of body composition was considered to be one of the best experimental methods for the evaluation of relative body fat precisely. The technique was based upon the Archimedian principle that loss weight in water was equivalent to the body volume. Density was then: body weight air/body weight air-body weight water. Once the body density or gravity was calculated from the UWW method it was relatively easy to use basic equations for determining %BF (Siri, 1961).

Bushkirk in 1961; Siri in 1961; Katch in 1968 mentioned that there were some inherent problems with UWW such as, the constants and assumptions used could be affected by variability in the amount of bone, the proportion of bone mineral, or by the state of hydration of the body. But, Brozek and Keys, in1951 claimed that UWW method was sufficiently reliable, and that the density of the lean body mass was relatively constant in healthy, young men (Cox, 1980).

Moreover, estimation of residual lung volume and assumption of the density of fat (0.907 approximately) and lean body tissue (1.100 approximately) were the limitation of the UWW (Wilmore, 1969).

Grirandola, Wiswell and Romero in 1977 demonstrated that dehydration decreased %BF, whereas fluid ingestion increase this value. They suggested that standards needed to be established for both exercise and state of hydration for a specified time period before subjects undergo UWW (Doğu, 1984)

Durnin (1974) measured total body density by underwater weighing on two hundred and nine males and two hundred and seventy-two females ages from sixteen to seventy-two years. Body fat was calculated using the equation of Siri developed 1956, although no significant difference arisen from the use of the equations of Brozek, Grande, Anderson and Keys. Mean body density for men, whose age was 20-29, was 1.064 ± 0.016 gm/ml and percent body fat was 15 % ± 7.0.

Matiegka in 1921 first proposed body fat could be computed from the product of surface area, six SKF thicknesses and a predictive constant (Cox, 1980).

Brozek and Keys published published the first valid SKF equations in 1951. Since that time, more than 100 prediction equations using various combinations of anthropometric variables had been reported in the literature (Jackson & Pollock, 1985; Lohman, 1981).

Because of the extensive laboratory equipment and time required to conduct UWW or water displacement determination of body density, the applicability of a convenient field method such as SKF measurements was obvious. Brozek and Keys in 1953 provided an early comprehensive review of the SKF measuring techniques. Edward in 1950 published the first classical anthropometric analysis of human subcutaneous fat derived from SKF measurements. He described 53 anatomical sites which would give excellent representation of the total body subcutaneous fat. The average SKF for men (20-35 years) was 412 mm. It was clearly obvious that fewer anatomical sites would have to be identified for the accurate prediction of body fat if the SKF method was to have broad applicability (Doğu, 1984).

One of the most popular and widely used SKF equations was developed by Jackson and Pollock (1978). This generalized equation was developed on a heterogeneous sample of 308 men ranging in age from 18 to 61 years and cross-validated on a similar sample of 95 men. The regression model was developed from the ∑7SKF(chest, midaxillary, triceps, subscapula, abdomen, suprailium, and thigh; R= .90, SEE=0.0078 g/cc). A high correlation (r= .98) was found between the ∑7SKF and the ∑3SKF (chest, abdomen, and thigh) thus, another equation using just three SKF sites was developed (R =.91l, SEE=0.0077 g/cc). Due to the enhanced feasibility of using only, three measurements compared to seven SKFs, Jackson and

Pollock (1985) suggested using the ∑3SKF equation. The cross-validation (Jackson & Pollock. 1978) proved successful for both equations, with SEEs identical to the validation sample (∑7SKF: r= .92, SEE=0.0078 g/cc; ∑3SKF, r=.92, SEE=0.0077g/cc). A similar model and generalized equations using the same ∑7SKF (R = .85, SEE = 0.0083 g/cc) and a different set of ∑3SKF (triceps, thigh, and suprailium (R=.84, SEE = 0.0086 g/cc) were also developed from a heterogeneous sample of 249 women ages 18-55 years and cross validated on a sample of 52 women (Jacson, Pollock,& Ward, 1980).

During the development of their equations, Jackson and Pollock (1978) made several noteworthy observations. First, the relationship between SKF and Db was quadratic. The prediction errors would be larger, especially at the extremes of body fatness, if a linear regression line were used to fit the data. Second, age accounted for a significant proportion of the variation in Db beyond that attributed to the ∑3SKF^{2}; therefore, age was independently related to body composition and should be a factor in generalized equations. The SKF method precisely measures Db; however, it requires a considerable amount of technical skill, being meticulous with site location and measurement, and is restricted to populations from whom the prediction equation was derived. Although an excellent field method to use on lean participants, it is difficult to obtain reliable and accurate readings on older participants with loose connective tissue or obese individuals with large folds (Wagner and Heyward, 1999).

Recently, the sum of seven (Sum7) and sum of three (Sum3) generalized skinfold equations of Jackson and Pollock (1978) has been shown to accurately estimate body composition (Colville, Heyward, & Sandoval, 1989; Eckerson, Housh, & Johnson, 1992; Jackson. & Pollock, 1978; Sinning et al., 1985).

Eckerson, Housh & Johnson (1992) reported that both the Sum7 and Sum3 equations were valid for estimating percent body fat. Therefore, the Sum3 equation, which requires fewer measures, was recommended for mass testing and field evaluations mostly.

Doğu (1984) studied to determine the predictability of %BF from SKF measurement on 18-25 years old Turkish male population and developed a regression equation to predict %BF from SKF measurements. The subjects of his study were 184 Turkish male from Ankara. Consequently, %BF estimated from two SKF (abdominal and thigh) was compared with underwater and 7 skinfold measurements. Correlation and standard error of estimation was found as r=0.71 and %3.548, respectively. The most significant formula was found in the abdomen and thigh sites as: %BF=2.662566 – 0.58197 x Abdominal + 0.2270 x thigh.

Zorba in 1986 tested the appropriateness of regression formula developed by Doğu in 1984 using same age group. But he did not found any differences at 0.05 significance level and this formula was accepted as valid.

Zorba in 1989 studied to develop an equation to predict the percent body fat of Turkish national wrestlers through skinfold method by using underwater weighting measurement as criterion. The subjects were 20 senior Turkish national and junior elite Turkish wrestlers. Skinfold measurements were taken from 7 sites.

Correlation of the new equation was found as 0.98 for senior wrestlers and 0.98 for junior elite Turkish wrestlers. The reliability of Green, Gale and Wilmore's equations were checked and none of them were found to be more reliable than new regression equations for this group of subjects. Besides, body fat values of Turkish junior and senior wrestlers of Ankara groups were compared and there were no significant differences between two groups.

Açıkada in 1990 examined body composition of 24 female athletes between the ages of 14-21 and 42 male athletes between the ages of 15-24. For both group of subjects, 4 different body density and 8 different fat %, fat mass, fat-free weight and fat-free mass protocols were used due to different combinations of methods in hydrostatic weighting, residual volume determination using Brozek et al. and Siri's formulas. For each protocol a separate multiple regression equation has been established. Applicability of the protocols in field situation was tested by having some of the coaches taking the anthropometric measurement for reliability. Some of the body density, fat %, fat weight, fat-free weight and %fat-free mass protocols showed within group variability at 0.05 significance level. Except for the wrist circumference, all the anthropometric measurements taken by the tester and coaches showed inter group differences at 0.05 significance level.

Kutlu in 1991 developed regression equations to predict minimal wrestling weight and percent body fat of the young Turkish wrestlers. The subjects of the study were 169 prepubescent boys aged between 11 and 13 years old. Underwater weighting, anthropometric measurements, skinfold measurements and vital capacity measurements were taken. Skinfold measurements were taken from 7 sites (abdominal, iliac, triceps, biceps, back, thigh and chest). The validity of Oppliger and

Tipton’s minimal wrestling weight equations were checked and none of them found to be more valid than new equations for this group. As a results revealed that new percent body fat equation was more reliable than Zorba’s equation for small Turkish wrestlers. Moreover, no big differences were found between foreign and Turkish groups on physical properties of wrestlers.

Because it was difficult to obtain accurate SKF measurements on older adults and obese individuals due to loose connective tissue and large fat folds, BIA was the preferred field method for estimating %BF in these populations. However, because the BIA method was based on impedance to electrical current flow the participant's state of hydration could influence the results; thus, strict guidelines for standardizing hydration levels prior to BIA testing needed to be followed (Heyward & Stolarczyk, 1996).

Deurenberg & Deurenberg in 2002, and Loy et al. in 1998 suggested that segmental instruments were easy to use and had an advantage of being relatively inexpensive as they were designed for costumer use. The hand-held bioelectrical impedance analyzer measured impedance from hand to hand, assuming that the amounts of body water in the arms was representative of the total body.

Generally, prediction formulae for body composition by BIA tended to be population specific due to cross-population differences in the parameters that were used in the equation (Norgan, 1995; Deurenberg, 1992).

Booth, Goddard & Paton (1966) compared the ultrasound, caliper and electrical conductivity for measuring fat thickness of forty-one-subjects, who were twenty-six men and fifteen women ranging in age from 16 to 87 years. In some subjects, measurements were made over the abdomen approximately 5 cm from the umbilicus and in others about 2.5 cm below the inferior angle of the scapula. All three methods were used in measurements over the abdomen, but only ultrasound and calipers were used at the infrascapular site. Abdominal fat thickness was measured by both ultrasonic and conductivity methods in twenty subjects, and by all three methods in fourteen subjects. The results of their study showed that there was an excellent correlation between ultrasonic and electrical conductivity methods. By contrast, caliper technique showed considerable variation compared with other two techniques, and this increased with increasing fat thicknesses.

In another study Bullen et al. (1965) investigated the possibility of using ultrasonic technique for the determination of fat thickness in humans. Further, the ultrasonic determination of subcutaneous fat at two sites were compared with the corresponding results obtained by skinfold calipers, and also a number of cases with measurement by the method of direct needle puncture (Quaade, 1956). Three sites (triceps, subscapular and abdomen) were selected and marked for measurement on the right side of the body. They examined total of one-hundred patients, 49 women and 51 men. According to the results the agreement between ultrasonic and skinfold measurement was good. Reliability coefficients at the triceps, subscapular and abdomen sites were being 0.98, 0.98, and 0.99, respectively. Results showed that ultrasound could be served as useful tool in body composition assessment.

Volz and Ostrove (1984) evaluated a portable ultrasonoscope in assessing the body composition of collage-age women. They measured subcutaneous fat thickness by US and SKF from seven sites and body density was measured by UWW technique. Mean Db was 1.0458 gm/cc, corresponding to a percent body fat of 22.8%. Correlation between US and SKF measurements were significant ($p<0.05$) at all sites. The highest was noted at the suprailiac (r=0.86) and the lowest was at the thigh (r=0.75). Four significant regression equation for predicting Db were developed, two utilized SKF and two utilized US measurements of tissue thickness. The equation with the greatest multiple correlation (R=0.80) utilized the suprailiac, subscapula, and thigh skinfolds. The equation using ultrasonic measurements taken at the suprailiac and thigh sites demonstrated a multiple correlation of R=0.78. Finally, they concluded that US was a reliable alternative to the SKF caliper in obtaining field measurements of body composition.

Fanelli et al. in 1984 designed a study to correlate ultrasonic and caliper measurements of subcutaneous fat with body density determined by hydrostatic weighing. Subcutaneous fat thickness was measured at seven body sites (triceps. biceps. subscapula. waist. suprailiac. thigh. and calf) with a skinfold caliper and an ultrasonic scanner. Regression equations to predict body density, and hence body fat, were derived for each technique using a minimal number of body sites. The sample consisted of 124 white men, aged 18 to 30 years. Mean body density determined by hydrostatic weighing was 1.07 g/ml (SD ± 0.01) and mean body fat was 12.7% (SD ± 5.8). Both ultrasonic and .caliper measurements of waist, thigh and triceps had the highest correlation with body density. Regression equations using these three sites in all possible two-site combinations were derived for each technique. The predictions of body density from these equations did not differ significantly. Their results suggested that in free-living, non-obese, white men, body fat could be estimated with nearly the same degree of accuracy using either the caliper or ultrasonic technique.

Frank (1984) determined the validity of arm radiography for quantifying total body fat in young and older men. One hundred subjects were measured for 1) body density by under water weighing with correction for residual air volume to estimate percent body fat and 2) horizontal right upper arm x-ray at KV76. These results demonstrate that the new arm radiogrammatic method is a reliable and valid technique for assessment of body composition in men ages 18-40 years. It permits quantification of relative body fat and thickness of muscle and bone for cross sectional and longitudinal analyses, as well as for clinical evaluation of nutritional status.

Mazess et al. (1990) reported that DEXA used a constant potential x-ray source and a K-edge filter (cerium) to generate two main energy peaks (40 keV and 70 keV). Roubenoff et al. (1993) claimed that he attenuation of soft tissue could be measured rather than assumed. With the participant lying supine on a padded table, an x-ray beam passed in a posterior to anterior direction through the bone and soft tissue upward to a detector. The ratio of x-ray beam attenuation at the lower energy relative to that at the higher energy was used to distinguish fat from the FFM (minus the bone component). The photon flux from an x-ray beam was greater than that of the ^{153}Gd isotope. The increased photon flux improved the resolution and precision of the image and reduces scan time (Lang et al., 1991; Wagner and Heyward, 1999).

Additionally, in the study of Lang et al. (1991) the radiation exposure was reported less for DEXA compared to DPX. The average skin dose of radiation was 1 to 3 mrad per DEXA scan which was comparable to the skin exposure from a week of environmental background radiation (about 3,5 mrad/wk; Lukaski, 1993).

Pietrobelli et al (1996) and Mazess et al. (1990) reported excellent short-term precision for DEXA. Ten measurements each on twelve participants were conducted over a period of one week. The authors reported a precision error for TBBM and

BMD of 50 g and < 0.01 g/cm2, or 1.8% and 0.8%, respectively. The errors for %BF in soft tissue, fat mass, and lean tissue mass were 1.4%, 1.0 kg, and 0.8 kg, respectively. The investigators also tested the precision of DEXA by measuring the BMD of an isolated skeleton. Intrascanner error was determined by measuring the same skeleton 34 times with one DEXA scanner, and interscanner error was assessed by measuring another skeleton on 37 different DEXA scanners.

Variation among DEXA manufacturers in the methods of calibration, data acquisition, and data analysis were cited as contributing to the questionable validity. However DEXA manufacturers have continued to make adjustments to their software (Lohman, 1996), and in more recent research by Kohrt (1995) using an updated version of sofware, DEXA accurately quantified additional packets of lard positioned over various areas of the body (Wagner and Heyward, 1999).

Additionally, Pietrobelli et al. (1996) showed that hydration changes had little effect on DEXA estimates. Such results provide encouraging evidence that DEXA emerged as an accurate method of assessing body composition.

Lohman (l992) reported that the error in Db from DEXA was only 0.0026 g/cc or just 1.2% BF for a homogeneous sample. In studies that compared two-component reference methods to a four-component model, investigators found DEXA to be a better predictor of mean %BF than hydrodensitometry, TBW, or potassium-40 measurements (Friedl, DeLuca, Marchitelli, & Vogel, 1992; Fuller, Jebb, Laskey, Coward, & Elia, 1992; Prior et al., 1997).

From the data of Friedl et al. (1992), DEXA underestimated mean fat mass by 0.3 kg corresponding to a mean underestimation of only 0.4% BF. The mean underestimation of %BF was a bit greater in the study by Fuller et al. (1,3%), but the investigators concluded that DEXA was a suitable alternative to hydrodensitometry or TBW for assessing % BF.

Prior et al. (1997) also validated whole body composition estimates from DEXA against estimates from a four-component model in a heterogeneous sample of 91 men and 8l women. They, too, reported no significant difference between methods (-0.4 ± 2.9%) with greater accuracy than hydrodensitometry. Furthermore, they concluded that DEXA measurements were not affected by race, athletic status, or musculoskeletal development.

Haarbo et al. in 1991 validated the use of dual energy X-ray absorptiometry (DEXA) for measurement of body composition. The precision error was expressed as the SD (CV%) for fat mass, FAT%, lean tissue mass, and total body bone mineral: 1.1 kg (6.4%), 1.6% (5.7%), 1.4 kg (3.1%), and 0.03 kg (1.2%), respectively. The accuracy study in vitro used (1) mixtures of water and alcohol, (2) mixtures of ox muscle and lard, and (3) dried bones. In the clinically relevant range of values there were only small influences on DEXA measurements of variations in amount and composition of the soft tissue equivalents. The accuracy study in vivo compared the components of body composition measured recently by DEXA and earlier by dual photon absorptiometry, counting of naturally occurring total body ^{40}K, and body density by underwater weighing in 25 healthy adult subjects. they found agreement between fat percentage (and lean body mass) by DEXA and the three established measurements modalities; mean differences were (-5.3 to -0.4%) and (-0.7 to 2.5 kg) for fat percentage and lean body mass, respectively. they concluded that DEXA provided a new method of measuring body composition with precision and accuracy errors, which were compatible with the application of DEXA in group research studies and probably also in clinical measurements of the single subject. Body fat mass (FM) was measured in 16 nonobese (BMI = 22.2 ± 2.2 kg/m^2) and in 21 obese (BMI = 34.5 ± 6.1 kg/m^2) women with DEXA, SKF, and BIA. Results revealed an obvious lack of agreement between the DEXA-BIA and DEXA-SKF methods in obese patients. In addition, FM was underestimated by BIA and SKF as compared to DEXA in both groups. Besides, better precision was obtained by DEXA method among the others.

Demura et al. in 2002 assessed the reliability and validity of three methods of bioelectrical impedance analysis (based on induction between the hand and foot, between one foot and the other foot and between one hand and the other hand) and the skinfold method, and to construct prediction equations for total body density by examining cross-validity in young Japanese adult males. The participants were 50 Japanese males aged 18-27 years (height 1.72 ± 0.06 m, body mass 64.9 ± 9.0 kg). Relative body fat based on underwater weighing was used as the criterion for validity. The reliability of all three bioelectrical impedance methods was high (R = 0.999). Three new prediction equations were constructed for the hand-foot method, foot-foot method and skinfold method. The relative body fat calculated using the new equations did not differ from that based on the underwater weighing method.

Belanowskii and Nilsson in 2001 assessed human body composition using dual-energy x-ray absorptiometry and bioelectrical impedance analysis. They used 100 consecutive subjects, 59 women and 41 men. The lean body mass (LBM), fat body mass (FBM), and percent body fat (%BF) were measured by the DEXA and BIA techniques. Their results showed highly statistically significant linear relationships between LBM, FBM and %BF assessed by DEXA and BIA in both sexes ($p<0.001$ for all measurements). No influence of age or BMI on the relationship between DEXA and BIA results was observed. Differences were observed between DEXA and BIA measurements of both fat and fat-free tissue. The results suggest that DEXA may underestimate the LBM and overestimate body fat compared with BIA, probably due to different assumptions about the constants. They concluded that both methods were suitable for body composition studies.

Barbosa et al. in 2001 compared percentage body fat (%BF) estimates by skinfold thickness (SKF), bioelectrical impedance analysis (BIA) and DEXA. Twenty voluntaries women were assessed. The body fat was estimated using two different equations of SKF (Jackson; Durning and Womersley), BIA using two-predictions formulas and DEXA. The %BF assessed by BIA shown poor correlation ($r < 0.5$) with two SKF equations. The %BF ranged from 31.5 ± 5.5 to 41.2 ± 6.1 for Jackson and DEXA , respectively. The analysis of variance showed no significant difference ($p > 0.05$) between methods and/or equations by BIA (RJL-Comp. Corp.) vs. DC-Jackson. There were observed significant differences ($p < 0.001$) between all comparisons. The correspondence between RJL-CompCorp vs. Deurenberg was good and the same was observed for DEXA vs. Durning and Womersley.

Kitano et al. in 2001 compared three methods for evaluating body composition: dual-energy X-ray absorptiometry (DEXA), skinfold thickness (Skinfolds), and bioelectrical impedance analysis (BIA). Subjects were 155 healthy young college-aged Japanese females whose mean ± SD (range) age, body height, body weight and body mass index (BMI) were 20.1 ± 0.3 (19.6-21.1) y, 158.9 ± 4.7 (145.4-172.6) cm, 52.0 ± 6.8 (39.4-84.6) kg and 20.6 ± 2.3 (16.5-32.5), respectively. Their mean skinfold thickness at the triceps and subscapular were 16.9 ± 4.7 (8.0-

31.0) and 16.0 ± 5.7 (7.0-40.0) mm, respectively. Mean body fat mass percentages evaluated by DEXA, Skinfolds and BIA were 29.6 ± 5.1, 22.8 ± 5.3 and 25.8 ± 4.7%, respectively. Body fat mass was 15.4 ± 4.4, 12.1 ± 4.5 and 13.6 ± 4.5 kg, respectively. Simple correlation coefficients between the three methods for body fat mass percentages provided the following coefficients: r=0.741 for DEXA vs. Skinfolds, r=0.792 for DEXA vs. BIA and r=0.781 for Skinfolds vs. BIA. Simple correlation coefficients for body fat mass were as follows: r=0.898 for DEXA vs. Skinfolds, r=0.927 for DEXA vs. BIA and r=0.910 for Skinfolds vs. BIA (all $p<0.001$). There were significant differences in the values among the three methods with the Skinfolds providing the lowest body fat mass and percentage, and DEXA the highest ($p<0.001$). They all appeared to be strongly correlated for evaluating body composition: however, different cut-off values for defining obese and lean needed to be defined for each method.

Deurenberg and Deurenberg-Yap in 2002 measured in 298 Singaporean, Chinese, Malay and Indian men and women using a chemical four-compartment model consisting of fat, water, protein and mineral (BF%4C). In addition, weight, height, skinfold thickness and segmental impedance (from hand to hand) was measured. Body fat percentage was predicted using prediction equations from the literature (for skinfolds BF%SKFD) and using the manufacturer's software for the hand-held impedance analyzer (BF%IMP). The subjects ranged in age from 18 –70 years and in BMI from 16.0 to 40.2 kg/m^2. The overall correlation between BF%4C and BF%SKFD was slightly higher than the correlation between BF%4C and BF%IMP and the SEE of the regression was slightly lower, indicating a slightly better predictive power from skinfolds. Experienced observers performed the skinfold measurements and it might well be possible that in the hands of less experienced observers, the impedance methodology would result in better estimates of body fat percentage than skinfold thickness measurements. The SEE for both methods used in this study was comparable with prediction errors for various methods found in other studies (Jebb et al., 2000; McNeill et al., 1991, Deurenberg et al., 1989, Durnin, and Womersley, 1974). As individual biases for both methods can be high, individual results should be interpreted carefully.

CHAPTER 3

METHODS AND PROCEDURES

All of the measurements were performed by skilled technicians at the Medical Center of Middle East Technical University in the same day following a 12 h fast (water intake was allowed). The subjects were instructed to avoid exercise for a minimum of 36 h prior to testing.

3.1. Selection of subjects

Two hundred eight Turkish university students aged between 18 to 26 years old participants participated in this study voluntarily. The study was approved by the ethical committee and written informed consent was obtained from each subject prior testing.

3.2. Test administration

All of the subjects were evaluated in the following sequence:

3.2.1. Collection of personal information

3.2.2. Height and weight measurements

3.2.3. BIA measurements

3.2.4. Skinfold measurements

3.2.5. Ultrasound measurements

3.2.6. DEXA measurements

3.2.1. Collection of personal information

All of the subjects' age, sex, weight, height, marital status, addresses and phone numbers were obtained before the measurements.

3.2.2. Height and weight measurements

Anthropometric measurements were obtained by the same operator according to conventional criteria and measurement procedures (Lohman, Roche, & Manorell, 1988). Body weight (Wt) and body height (Ht) were measured twice, and the average was used as the final score. Wt was measured to 0.05 kg using a standard beam balance (Soehnle, Germany), in swimming clothes. Ht was measured to the nearest 1 mm using a Harpenden stadiometer (UK). Body mass index (BMI) was calculated using the formula: BMI (kg/m^2) = Wt (kg)/Ht^2 (m^2).

3.2.3. BIA measurements

BIA measurements were performed by an OMRON BF300 Body Fat Monitor (Osaka, Japan) (BFM) using the standardized protocol, which was described by the manufacturer (Omron manufacturer's manual). The % fat estimates of the BIA used in the present investigation was generated by the instrument. Subjects held BFM standing with both feet slightly apart and their arms out straight at 90° to their body without bending their elbows. Moreover, they did not move during the measurement.

3.2.4. Skinfold measurements

The SKF including two layers of skin and subcutaneous fat was lifted from the underlying muscle between the ends of the thumb and index finger. The fold was held for the duration of the reading, applying the caliper approximately one centimeter from the fingers (Adams, 1998).

SKF measurements were obtained on each subject at three sites by the same investigator who had previously shown test-retest reliability of r =0.89 using a standard Holtain LTD caliper (10 g/mm constant pressure). Three skinfolds sites, which were taken as described by Jackson and Pollock (Jackson, & Pollock, 1985) for men were: (1) chest; (2) abdomen; and (3) thigh; those for women were: (1) triceps; (2) suprailiac; and (3) thigh.

Each site was located visually and marked so that consequent trials of measurements were at the identical site. Each measurement was repeated until three identical readings were taken from all sites and the average of the three values was calculated for subsequent analysis.

Skinfold measurements were taken on the right side of the body while the subject was standing erect with his/her arms by his/her sides as suggested by Jackson and Pollock (Jackson, & Pollock, 1985).

Among the many available equations for converting anthropometric data into the respective body density (D_b), generalized Sum3 skinfold equations of Jackson and Pollock (Jackson, & Pollock, 1978) was chosen and converted to % BF using the revised formula of Brozek et al. (Brozek et al, 1963).

The locations of the skinfolds at the three sites were;

1. Triceps-A vertical fold was picked up about 1 cm on the back of the arm,

midway between the tip of the acromion process of the scapula and the olecranon process of the ulna. The mid-point was measured with the arm flexed at the elbow; the skinfold was lifted parallel to the long axis of the arm with the arm hanging freely at the side.

2. Chest- A diagonal fold was lifted one-half of the distance from the anterior axillary line (the front of the armpit) toward the nipple.

3. Suprailiac-A slanted fold was lifted in the midaxillary line at the level of the iliac crest of the ilium from the anterior part of the body.

4. Abdomen-A horizontal fold, which was located 2 cm from the umbilicus on the right side of the body, was lifted.

5. Mid-thigh-A vertical fold was lifted about 1 cm from the midline of the front of the thigh halfway between the inguinal ligament and the top of the patella while the body weight shifted on to the left leg and right leg is relaxed but not lifted off the floor.

3.2.5. Ultrasound measurements

Subcutaneous fat tissue thickness was measured at identical sites of SKF measurements by an ultrasonoscope (GE LOGIQ ^{TM} α200). The instrument's probe (transducer) emitted pulses of sound in the frequency of 2.5 MHz while also acting as a receiver for the returning echoes.

The US was calibrated each day before testing, against a 40-mm plastic block, which was provided with the instrument. Ultrasonic determinations were performed immediately after the SKF measurements by an experienced operator. A minimum of two readings were obtained at each site; if these values agreed within 1 mm, the readings were averaged together and recorded. However, if there was a discrepancy of greater than 1 mm, a third or fourth reading was taken and the two closest values were then averaged and recorded. The procedure was performed as follows: (a) each site was carefully selected and marked to insure repeatability of measurement; (b) a few drops of ultrasound gel were applied to the surface of the probe; (c) the transducer was applied to the skin at a 90° angle to the bone; (d) the gain knob (echo sensitivity monitor) was turned toward maximum causing the illumination of all diodes, then slowly turned counterclockwise, reducing sensitivity until only one or two diodes remained illuminated (representing the bottom of the fat layer); finally, (e) pressure on the probe was reduced with the distance (indicated just prior to disappearance due to the removal of the probe) recorded as the depth of the subcutaneous fat layer. In this manner, consistency in probe pressure was obtained.

3.2.6. DEXA measurements

DEXA measurements were made with a total body scanner (model DPX-L, Lunar, Madison, WI, software version 3.6) that used a constant potential X-ray source at 78 kVp and a K-edge filter to achieve a congruent beam of stable, dual-energy radiation with effective energies of 40 keV and 70 keV. The detector system collects data from 120 pixels during each traverse as the scanner proceeds rectilinearly over the scanned subject (Elowsson et al., 1998).

The estimations of fat and lean mass are based on extrapolation of the ratio of soft tissue attenuation of the two X-ray energies in non-bone–containing pixels. The software performs calculations of the differential attenuations of the two photon energies and presents data for each subject of percentage of fat, fat mass (g), lean mass (g), bone mineral mass (g), bone mineral density (BMD) in g/cm^2 and total weight. According to the manufacturer, a CV for human BMD of 0.5% can be expected during repeated measurements.

Daily quality-assurance tests were performed according to the manufacturer's instructions. The entire body of each subject was scanned, beginning at the top of the head, with the "medium" scan mode. Measurement time was about 20 min.

All scans were performed and analyzed by the same operator. FM was calculated from the soft tissue attenuation ratio (Rst), which was defined as the ratio of beam attenuation at the lower energy relative to the higher energy. %FM and FFM (kg) were calculated respectively as: %FM=100 x FM (kg) / [FM (kg) + SFFM (kg) + BMC (kg)]; FFM (kg)=[SFFM (kg) + BMC (kg)]. The reproducibility of the DEXA instrument for different body composition measurements has been previously published (De Lorenzo , Andreoli, & Candeloro, 1997).

Previous test-retest reliability data for DEXA from the authors' laboratory indicated that for young adult male subjects (N = 16) and female subjects (N=16) aged between 18-26 measured 24-72 h apart, the intraclass correlation (R) was 0.99 with measurement of 0.9% fat.

3.3. Statistical analysis of data

Statistical Program for Social Sciences 10.0 (SPSS 10.0) for Windows package program was used for statistical analysis. Results are expressed as mean ± SD. In order to examine the correlation between the three of SKF and US sites and %BF obtained from DEXA, Pearson Correlation Coefficient analysis was conducted for males and females. Differences among DEXA, SKF, US, and BIA in estimating

%BF were examined by conducting series of paired t-test for male and female separately.

The %BF of subjects calculated through DEXA was used as dependent variables in a multiple regression analysis while the SKF and US measurements of the same subjects were used as independent variables. The multiple regression analysis produced a constant, regression value for each one of the three SKF and US measurements, in an order of correlations to the actual percent body fat value from high to low. From these results a regression equation was obtained to calculate predicted percent body fat.

CHAPTER 4

RESULTS

This study was designed to examine the correlations between the SKF and US measurements of subcutaneous fat at specified anatomical sites, correlations among the SKF, US, BIA and DEXA, and differences among %BF values of sedentary male sand female university students measured by DEXA, SKF, US and BIA in order to prove the hypotheses. The present investigation was also designed to developed regression equations to predict %BF value from the anthropometric measurement of SKF and US from the three sites by comparing those values obtained from DEXA.

Two hundred eight subjects participated in the study. All the participants were sedentary university students, age ranging between 18-26. Half of the subjects were male and the other half were female. The descriptive characteristics of the participants participated in the study are presented in Table 1.

Table 1. Means, standard deviations, and range of the subject's age, height, weight, BMI, BMD and %BF.

Measurement	Male (N=104)			Female (N=104)		
	Mean	S.D.	Range	Mean	S.D.	Range
Age (yr)	22.2	2.5	18-26	21.9	1.9	18-26
Height (cm)	176.8	5.9	164-190	165.2	6.2	150-180
Weight (kg)	74.9	10.4	55-120	55.6	7.9	42-88
BMI (kg/m^2)	23.9	2,6	18.6-34.3	20.3	2.4	16.7-32.3
BMD (g/cm^2)*	1.241	0.009	1.01-1.51	1.120	0.006	0.9-1.1
%BF (DEXA)	18.5	6.2	7-34	28.4	6.6	12.3-51.1

* Derived from DEXA.

Table 1 revealed the mean age, height, weight, BMI, BMD, and %BF of the subjects. The mean age was 22.2 ± 2.5 with the range of 18-16, the mean height was 176.8 ± 5.9 with the range of 164-190, the mean body weight was 74.9 ± 10.4 with the range of 55-120, the mean BMI was 23.9 ± 2.6 with the range of 18.6-34.3, the mean BMD was 1.241 ± 0.009 with the range of 1.01-1.51, and the mean % BF was 18.5 ± 6.2 with the range of 7-34 for males. The mean age was 21.94 ± 1.9 with the range of 18-26, the mean height was 165.2 ± 6.2 with the range of 150-180, the mean body weight was 55.6 ± 7.9 with the range of 42-88, the mean BMI was 20.3 ± 2.4 with the range of 16.7-32.3, the mean BMD was 1.120 ± 0.06 with the range of 0.94-1.12, and the mean % BF was 28,4 ± 6.6 with the range of 12.3-51.1 for females, respectively. Finally, Table 1 showed that the male had statistically significant higher mean values of height, weight, BMI, BMD than those of female, except than that of %BF. Moreover, the male had significantly more LBM and the female significantly more body fat, when assessed by DEXA.

In order to examine the correlation between the three of SKF and US sites and %BF obtained from DEXA, Pearson Correlation Coefficient analysis was conducted for males and females. The means, standard deviations, standard errors, ranges and individual correlations of each of the three SKF and US measurements, and %BF obtained from DEXA were presented in Table 2.

Table 2. Means of the three SKF and US sites and their correlation to % BF derived from DEXA.

Site (N=104)	Mean	S.D.	S.E.	Range	r†
SKF Male					
Chest (mm)	9.6	4.8	0.5	2.6-24.8	0.85*
Abdomen (mm)	21.8	10.7	1.1	4.6-44.2	0.85*
Thigh (mm)	13.2	5.5	0.5	4.4-30	0.83*
SKF Female					
Triceps (mm)	15.9	5.8	0.6	5-37.6	0.82*
Suprailiac (mm)	12.3	6.4	0.6	3.6-37.6	0.72*
Thigh (mm)	24	6.6	0.6	11.8-42.4	0.81*
US Male					
Chest (mm)	4.5	2.9	0.3	0.9-14.8	0.86*
Abdomen (mm)	12.9	7.9	0.8	1.9-41.3	0.86*
Thigh (mm)	5.7	2.8	0.3	1.5-14.5	0.83*
US Female					
Triceps (mm)	8.7	3.6	0.4	1.9-24	0.77*
Suprailiac (mm)	7.1	3.9	0.4	1.3-20.3	0.72*
Thigh (mm)	12.6	4.2	0.4	5.8-27	0.81*

* Significant at $p<.001$.
†Correlation based on log (measurement) transformation.

Results of the analysis presented that the highest mean values were recorded in the abdomen site of SKF and US (21.8 and 12.9mm, respectively) measurements for male. Similarly, the highest mean values were recorded in the thigh site of SKF and US (24 and 12.6mm, respectively) measurements for female. The lowest mean values were recorded in the chest site of SKF (9.6mm) and in the site of US (4.5mm) for male. For female, the lowest values were recorded from the suprailiac SKF (12.3mm) and ultrasound (7.1mm) sites.

The correlation coefficient between %BF and US was found to be 0.86 and between %BF and SKF was 0.85 in the chest and abdomen sites for male. These coefficients were found to be 0.81 and 0.82 in the triceps and thigh sites for female, respectively.

In order to find whether there was a significant difference between the US measurement and one-half of the SKF thickness at each site series of paired t-test were conducted for males and females separately. The results of the paired t-test are shown in Table3.

Table 3. Differences between one-half SKF and US measurement of subcutaneous fat.

Site (N=104)	Mean US	Mean ½ SKF	US-1/2 SKF	t_{value}
Male				
Chest (mm)	4,5	4,8	-0,3	-2.9*
Abdomen (mm)	12,9	10,9	2	5.9**
Thigh (mm)	5,7	6,6	-0,9	-13.1**
Female				
Triceps (mm)	8,7	7.9	0,8	5.5**
Suprailiac (mm)	7,1	6,2	0,9	6.6**
Thigh (mm)	12,6	12	0,6	3.3*

* p<.005
** p<.001

The results revealed that there were significant mean differences between the US measurement and one-half of the SKF thickness at each site. The highest difference was observed between the US measurement and one-half of the SKF thickness in the abdomen site (2mm) for males. The highest differences were recorded in the suprailiac site (0.9mm) for females.

In order to find whether there were significant differences between DEXA and SKF, US, and BIA in estimating %BF series of paired t-test were conducted for male and female separately. The results of the paired t-test were presented in Table 4 for males and in Table 5 for females, respectively.

Table 4. Differences between mean values, standard deviations, and t value of DEXA and SKF, US, and BIA for males.

Variable	Mean	S.D.	t_{value}
DEXA %BF	18.53	6.18	
SKF %BF	12.43	5.61	-26.1***
US %BF	11.98	7.82	-19.9***
BIA %BF	13.70	4.9	-13.5***

*** p<.001

Results of the paired t-test revealed that there were significant differences between DEXA and SKF, US, and BIA measurements for males. According to these results, the mean %BF derived from DEXA (M=18.53, SD=6.18) was significantly greater than the mean %BF derived from SKF (M=12.43, SD=5.61), t(103)=-26.1, p<.001, US (M=11,98, SD=7.82), t(103)=-19.9, p<.001, and BIA (M=13,70, SD=4.9), t(103)=-13.5, p<.001.

Table 5. Differences between mean values, standard deviations, and t value of DEXA and SKF, US, and BIA for females.

Variable	Mean	S.D.	t_{value}
DEXA %BF	28.40	6.63	
SKF %BF	20.82	5.26	-25.9***
US %BF	24.98	7.38	-10.2***
BIA %BF	19.16	5.19	-22.1***

*** p<.001

Results of the analysis revealed that there were significant differences between DEXA and SKF, US, and BIA measurements for females. According to these results, the mean %BF derived from DEXA (M=28.40, SD=6.63) was significantly greater than the mean %BF derived from SKF (M=20.82, SD=5.26), t(104)=-25.9, p<.001, US (M=24,98, SD=7.38), t(103)=-10.2, p<.001, and BIA (M=19,16, SD=5.19), t(103)=-22.1, p<.001.

In order to developed regression equations to predict %BF multiple regression analyses were conducted for males and females separately. Regression analysis of %BF was performed on the logaritmically-transformed SKF and US data.

The data were analyzed using the stepwise regression procedure, with %BF obtained from DEXA serving as the dependent variable and subcutaneous fat thickness at three designated sites as the independent variables. Results of the analyses revealed that the highest multiple correlations with %BF obtained from DEXA were recorded in the chest (.85) and abdomen (.85) SKF, and in the chest (.86) site from the US measurements for males. The highest correlations were recorded in the triceps (.82) SKF and thigh (.81) site from the US measurements for females. From these variables, eight statistically significant equations, four under each measurement condition, were presented in Table 6. Within each group of equations, the highest first-order linear correlation was presented along with the greatest multiple correlation utilizing the minimum number of significant sites.

Table 6. Regression equations for predicting % BF from SKF and US measurements (N=208).

Equation* (N=104)	r	R^2	SEE
SKF for Male			
(1) $Y' = -8.642 + 13.435 (X_1) + 11.495 (X_2)$	0.885**	0.783	2.909
(2) $Y' = -13.531 + 10.301 (X_1) + 6.313 (X_2) + 13.331 (X_3)$	0.924**	0.854	2.402
SKF for Female			
(3) $Y' = -13.249 + 35.483 (X_2)$	0.820**	0.672	3.816
(4) $Y' = -27.988 + 17.477 (X_2) + 8.467 (X_4) + 19.854 (X_6)$	0.908**	0.824	2.827
US for Male			
(5) $Y' = 2.570 + 11.040 (X_7) + 9.427 (X_9)$	0.899	0.809	2.73
(6) $Y' = 0.947 + 9.439 (X_7) + 4.816 (X_9) + 10.310 (X_{11})$	0.930	0.865	2.306
US for Female			
(7) $Y' = -15.175 + 40.352 (X_{12})$	0.818**	0.669	3.836
(8) $Y' = -10.896 + 10.990 (X_8) + 8.641 (X_{10}) + 20.910 (X_{12})$	0.895**	0.801	3.002

* Key: X_1= log male chest SKF
X_3= log male abdomen SKF
X_5= log male thigh SKF
X_2= log female triceps SKF
X_4= log female suprailiac SKF
X_6= log female thigh SKF
X_7= log male chest US
X_9= log male abdomen US
X_{11}= log male thigh US
X_8= log female triceps US
X_{10}= log female suprailiac US
X_{12}= log female thigh US

** $p<.001$

Results of the regression analysis presented that SKF measurement of subcutaneous fat at three-sites gave the best prediction to percent body fat for males and females separately. Multiple correlations using three sites simultaneously were r=0.92, SEE=2.44 and r=0.91, SEE=2.8 for male and female, respectively. In the same way, US measurements of subcutaneous fat at three-sites gave the best prediction to percent body fat for males and females separately. The multiple correlations using three sites simultaneously were r=0.93, SEE=2.3 and r=0.90, SEE=3.0 for males and females, respectively.

CHAPTER 5

DISCUSSION

The purpose of this study was to examine the correlations between the SKF and US measurements of subcutaneous fat at specified anatomical sites, correlations among the SKF, US, BIA and DEXA, and differences among %BF values of sedentary male and female university students measured by DEXA, SKF, US and BIA. The present investigation was also designed to developed regression equations to predict %BF value from the anthropometric measurement of SKF and US from the three sites by comparing those values obtained from DEXA.

Results of the current study suggested that there was a tendency for the three (SKF, US, BIA) methods to underestimate fat content in males and females, as compared with DEXA (Table 4 and Table 5).

First, there are significant differences ($p<0.001$) between %BF obtained from DEXA and SKF for male and female separately. It was apparent that the SKF method underestimated fat content in both males and females. This difference may arise from: 1) low accuracy in the amount of tissue picked up to form the skinfold, 2) difficulty in palpating the fat-muscle interface, 3) SKF thickness may exceed the maximum opening of caliper, 4) caliper tips may slide on larger skinfolds, 5) subsequent readings in subjects may be decreased due to repeated compression of subcutaneous fat, 6) differences in elastic properties of both fat and skin tissues between the individuals, and 7) subject discomfort (Kuczmarski, Fanelli & Koch, 1987).

Jackson (1988) has also emphasized a number of statistical and research design problems that existed in past research designed to predict body density from skinfolds and other anthropometric measures. These problems have included using samples that were too homogeneous and too small, using too many independent variables for the number of subjects, using linear regression equations to describe nonlinear relationships, placing too much emphasis on stepwise multiple regression analysis, and failing to cross-validate prediction equations developed.

Moreover, important potential sources of measurement error associated with skinfold measurements are caliper selection and tester reliability, including inter- and intra observer measurement error and the variance associated with the selection of skinfold site (Pollock & Jackson, 1984). Differences in skinfold fat reading may result from the use of different calipers. According to Edwards et al. (1955), the pressure exerted by the caliper has a significant effect on both the skinfold measurement and the consistency with which the measurement is repeated. However, there were no systematic differences between measurements at any site among the calipers. In this study intra tester reliability of SKF was .89 for four measures (chest, triceps, abdomen, thigh). Additionally, caliper, which is used in this study, can be either different from the caliper used in the formulation of Jackson & Pollock (1985), or there may be differences in terms of calibration.

The best way to avoid inter observer variability is to have the same investigator take all the measurements. Lohman et al. (1984) showed significant variation in skinfolds when experienced testers did not practice together or standardize procedures. One 30-min practice session minimized such errors. Jackson, Pollock, and Gettman (1978) investigated inter tester reliability of SKF measurements and percent fat, and found that the variation among experienced testers who had practiced together was a relatively small source of measurement error (inter tester reliability estimates exceeded .93). These results agree with findings reported by others (Keys & Brozek, 1953; Munro, et al., 1966). It could not be an error arosen from intraobserver in this study, because all SKF measurements were taken by the same investigator. However, the reason of low %BF, calculated from SKF measurements, can not come from intraobserver error. The difference might result from other things.

Besides to the errors mentioned above, the SKF method relies on several assumptions. One was that SKF was a good measure of subcutaneous fat. Another assumption for the SKF method was that there was a good relationship between subcutaneous fat and total body fat. For Behnke's (1969) reference participants, it was estimated that subcutaneous fat made up one third of total fat. However, Lohman (1981) noted that subcutaneous fat could range from 20 to 70% of total fat depending on such biological factors as age, sex, and degree of fatness. Consequently, SKF appears to be an insufficient measurement technique to predict %BF of the subjects used in the present study, which is measured by DEXA.

Additionally, race could be a factor as Vickery, Cureton, and Collins (1988) suggested that blacks might store a greater percentage of total body fat internally, compared to whites.

Lohman (1981) analyzed several potential sources of error in the SKF method, including variation in subcutaneous to total fat, variation in SKF thickness to subcutaneous fat, and technical error in the SKF measurement. From these variations, Lohman theorized that the total error of estimation (biological plus technical) of fat content from SKF thicknesses was 3.3% BF Total variation in the relation of SKF to Db was estimated at 0.0098 g/cc. This was certainly an improvement beyond using only height and body weight to estimate body fatness.

The bias in %BF predicted from SKFs was also different among the ethnic groups, with age and level of body fat as confounders. Many studies were found a relationship between bias and both body fat level and SKFs (Wang et al., 1999; Deurenberg & Wang, 1995; McNeill et al., 1991), and this could be explained with increasing body fat, relatively more fat was stored internally and this fat escaped from the measurements taken when using SKF calipers. In many studies UWW is used as reference method to calculate Db from SKF measurements, but it is not free from measurement errors and may be biased too (Heymsfield et al., 1997; Deurenberg, 1992; Baumgartner et al., 1991).

UWW considering as a reference method has been used to development of SKF regression equations until now. However, there are some assumptions in the UWW. Wedgewood (1963) has emphasized the fact that densitometry is a based on four interrelated assumptions: 1) the LBM has a constant density; 2) the LBM has a constant proportion of water; 3) bone is a constant proportion of the LBM; and 4) cell water is a constant proportion of cell mass (Wilmore, Girandola & Moody, 1970).

Percent fat is usually predicted from either the Siri (1961) or the Brozek et al.

(1963) equation. The Siri formula avoids the assumption of a constant water content of the FFM and allows correction for abnormal hydration. However, it is still based on the assumption that fat density is 0.900 g/cc and FFM density is 1.100 g/cc (30). The equation of Brozek et al. (1963) utilizes the concept of a reference man of a specified D_b and body composition (15.3% fat). Within D_b of 1.09 and 1.03 g/cc, the two formulas agree within 1 % fat (Lohman, 1981).

Although universally accepted, the Siri and Brozek equations are not without problems. Both are based on the results of direct compositional analysis of human cadavers, but only a few cadavers were used and they did not represent a distribution of the normal population (Pollock & Wilmore, 1990; Behnke & Wilmore, 1974). As previously mentioned, the density of FFM and fat are quite variable in humans (Clarys, Martin & Drinkwater, 1984) and can cause an error in estimating percent fat from D_b by 2.5% to 3.8% (Lohman, 1981).

The difference between the results obtained from SKF in the present study and the measurements of dexa, which is assumed to be the reference method of measuring %BF, may result from regression equation obtained from UWW. The cause of difference in %BF obtained from SKF than those of DEXA results from regression equation obtained from UWW.

There were several studies which shown similar results with the present study in literature (Erselcan et al., 2000; Barbosa et al., 2001; Kitano et al., 2001). In the study of Erselcan et al. in 2000, the degree of agreement between SKF and DEXA methods were assessed in obese and non-obese patients. Results revealed an obvious lack of agreement between the DEXA and SKF methods (r=0.75) in obese patients. But there was a high correlation between the DEXA and SKF methods in regression line analysis in nonobese subjects as $R^2=0.89$. In addition, according to the Bland and Altman method. FM was underestimated by SKF as compared to DEXA in both groups. Besides, better precision was obtained by DEXA than SKF.

Moreover, Barbosa et al. in 2001 compared %BF estimates by SKF thickness and DEXA. The body fat was estimated using two different equations of SKF (Jackson; Durning and Womersley) and DEXA. The %BF assessed by two SKF equations shown poor correlation ($r < 0.5$) with DEXA. The %BF ranged from 31.5 ± 5.5 to 41.2 ± 6.1 for Jackson and DEXA, respectively. There were observed significant differences ($p < 0.001$) between two comparisons.

Similarly, Kitano et al. in 2001 evaluated body composition of 155 healthy young college-aged Japanese females by DEXA and SKF. Simple correlation coefficients between the two methods was $r=0.741$ for DEXA vs. SKF. SKF provided lower body fat mass and percentage than DEXA ($p<0.001$).

Second, there are significant differences ($p<0.001$) between %BF obtained from DEXA and US for male and female separately. Like SKF, it was apparent that the US method also underestimated fat content in both males and females. The cause of this difference may come from the formula using for calculation of %BF. The formula using for calculation of %BF that obtained from SKF equation was also applied to the ultrasound data because the US measures the same subcutaneous fat layer. Any studies comparing US with DEXA or other reference measurements, that estimate body compositions could not be found in the previous studies. Therefore, a comparison between US and other reference measurements is not possible.

As mentioned before, SKF measurement that obtained from subcutaneous fat thickness gave significantly lower results compared with DEXA. Like SKF, US has also measured subcutaneous fat thickness and the similar formula was used to find %BF estimated from US like in the SKF measurements in this study. Therefore, it is natural that results of US give the significantly lower %BF compared to DEXA like in SKF.

Third, there are significant differences ($p<0.001$) between %BF obtained from DEXA and BIA for male and female separately. Like SKF and US, it was apparent that the BIA method underestimated fat content in both males and females. Results of the analyses shows that although BIA gives the nearest score, it still underestimates %BF in male subjects according to DEXA. Unlike males, BIA gives the lowest score but still underestimates %BF in females compared with DEXA. The actual cause of this difference is not known. Because, bioelectrical impedance assesses the amount of water in the body and is used to calculate %BF assuming a constant hydration of the fat-free mass (Jebb et al., 2000; Wang et al, 1999).

Segmental impedance analysis, where it is assumed that the water content of the measured body segment is considered as representative of the total body, was used in the present study. However, there are several deficiencies of this assumption. These are presented as the followings;

Segmental impedance measurements, like total body impedance measurements, are also affected by the length of the extremities (Fuller and Elia, 1989; Baumgartner ,Chumlea, and Roche, 1989; Lukaski et al., 1985). Subjects with relatively longer arms or with thinner arms are higher arm impedance values compared to their counterparts with shorter or thicker arms, also when the total amount of water in the arms is equal (Snijder, Kuyf, & Deurenberg, 1999).

Additionally, the hand-held impedance analyzer measures impedance from hand to hand, assuming that the amount of body water in the arms is representative of the total body. With increasing age, the amount of body fat in the trunk increases (Deurenberg-Yap et al., 2001; WHO report, 1998; Forbes, 1987) and this is not taken into account when segmental impedance is measured. In addition, the amount of intra-muscular fat increases with increasing age, also in the arms, which will affect the relationship between arm impedance and total body water/fat-free mass. Further, the distribution of extra and intracellular water changes toward a higher relative amount of extracellular water with increasing age, and impedance at 50 kHz frequency is not fully capable of distinguishing between the two (Deurenberg, & Deurenberg-Yap, 2002).

Belanowskii and Nilsson in 2001 assessed human body composition using DEXA and BIA in 100 consecutive subjects, 59 women and 41 men. Their results showed that DEXA might underestimate the LBM and overestimate body fat compared with BIA ($p<0.001$ for both sexes), probably due to different assumptions about the constants.. The results of Belanowskii and Nilsson's (2001) study are similar to the findings of this study.

Moreover, In the study of Deurenberg, & Deurenberg-Yap (2002), calculated %BF by a chemical four-component model that accepted reference method in literature was compared with hand to hand BIA and results showed that BIA gave significantly ($p<0.05$) low outcomes than chemical four-component model. These results also support the findings of this study too.

According to the results of the paired t-test, SKF showed similar results in comparison with US than did BIA for males. Although BIA gave the nearest estimation of %BF, there was still significantly underestimate %BF as compared with DEXA. Unlike males, SKF showed almost similar results in comparison with BIA than those of US for females. Although US gave the nearest estimation of %BF value for females, it was also underestimate %BF significantly as compared with DEXA like SKF and BIA. As a conclusion, %BF value obtained from DEXA was significantly higher than those values obtained from SKF, US and BIA for both males and females.

The comparison of the methods revealed that the three techniques were not used interchangeable. The mean %BF obtained from DEXA was significantly higher than those obtained from SKF, US or BIA measurement, which also differed significantly in their own. Moreover, the limits of agreement among methods were quite wide for clinical and field use. The reason for the lack of agreement among these four methods (DEXA, SKF, US, BIA) is not well known.

Finally, results of the present investigation indicated that the generalized regression equations were quite reliable and valid for sedentary Turkish male and female university students aged between 18 and 26 (Table 6). The logarithm of the chest and abdomen SKF values was the single best predictor of %BF for males when compared to other SKF measurements. The regression analysis developed for this site (Table 6, equation 1) had a high correlation coefficient of r=0.89 and SEE, 2.9%. Unlike males, the logarithm of the triceps SKF value was the single best predictor of %BF for females when compared to other SKF measurements. The regression analysis developed for this site (Table 6, equation 2) had a relatively high correlation coefficient of r=0.82 and SEE, 3.8%. These two equations would be little use in predicting %BF because of relatively large amount of error that would be introduced. The best fitting multiple regression equation included three SKF sites both for males and females (Table 6, equation 2 and 4). These equations, using the chest, abdomen, and thigh SKF for males and triceps, suprailiac and thigh for females, demonstrated the highest multiple correlations r=0.92 along with low SEE=2.4% for males and r=0.91 along with low SEE=2.8% for females.

Several investigators have published skinfold regression equations with multiple correlations that ranged from R=0.68-0.80 (Durning & Rahaman, 1967; Katch & McArdle, 1970; Katch & Michael, 1968; Sloan, Burt & Blyth, 1962; Wilmore & Behnke, 1970) and usually included a minimum of two sites. In addition to the suprailiac, the subscapula, and the thigh, some equations have included the triceps skinfold (Wilmore & Behnke, 1970).

Regression analysis of %BF on US measurement was performed in a similar manner. As with the SKF equation, the logarithm of the chest and abdomen US values was the single best predictor of %BF for males (Table 6, equation 5) with high correlation coefficient of r=0.90 and SEE, 2.7%. Unlike males, the logarithm of the thigh US value was the single best predictor of %BF for females when compared to other US measurements. The regression analysis developed for this site (Table 6, equation 7) had a relatively high correlation coefficient of r=0.82 and SEE, 3.8%. These two equations would be little use in predicting %BF because of relatively large amount of error that would be introduced. The best fitting multiple regression equation included three US sites both for males and females (Table 6, equation 6 and 8). These equation, using the chest, abdomen, and thigh US for males and triceps, suprailiac and thigh for females, demonstrated the highest multiple correlations r=0.93 along with low SEE=2.3% for males and r=0.90 along with low SEE=3.0% for females.

In the results of Volz and Ostrove's (1984) study, although the triceps had a slightly higher correlation to Db (r=-0,61) than thigh (r=-0.57), it did not account for much of the variation in Db or increase the predictive value of the equation once the other two sites were included, although the thigh measurements did increase the predictive value for women.

Although there are some regression equations developed from SKF and US measurements to determine %BF using UWW as a reference method, there was no study encountered in the previous studies that developed regression equations to determine %BF from SKF and US measurements using DEXA as a reference method.

Some researchers evaluated the differences between SKF and US measurements, compared in terms of %BF obtained from UWW, in the previous studies. For example, the results of Volz & Ostrove (1984) and Fanelli & Kuczmarski (1984) were consistent with the result of the present study. They found that the mean values for %BF generated from the formulas using caliper measurements are not significantly different from those derived from US measurements.

In the study of Fanelli & Kuczmarski (1984), US and SKF measurements from the triceps, waist and thigh sites were taken from males. Correlations between SKF and US were also investigated. They found that US measurement of subcutaneous fat at the waist and thigh sites gave the best prediction of body fat. The multiple correlation using two sites simultaneously was r=0.81 for US and r=0.77 for SKF in males. The results of their study were consistent with the result of our study.

Similarly, Volz & Ostrove (1984) took measurements from the biceps, triceps, subscapula, suprailiac, abdomen, thigh and calf sites in females and investigated correlations among them. They found that US and SKF measurement of subcutaneous fat at the suprailiac site gave the best prediction of body fat. The multiple correlation using one site was r=0.70 for SKF and r=0.74 for US in females. The results of their study were inconsistent with the result of the present study.

In summary, as considering DEXA as a reference method, SKF, US and BIA give different outcomes. This outcome showed that regression equations developed from previous studies by using SKF and US and equation inside the software of hand to hand BIA was not appropriate for the group of this study. These results revealed that new regression equations should be developed or existing equations should be revised for the different populations come from different ethnicity.

With the new regression equations, the US appears to be a reliable, portable, and non-invasive tool which can be used by any field investigator on obese or thin inidviduals like SKF calipers. As it is known, SKF measurements are prone to subjective errors, and training is necessary before the investigators become efficient in their uses. In addition, they present a problem while measuring obese individuals. So, the probability of making mistake in US measurements is less than those of SKF measurements. However, there are some drawbacks of the ultrasonoscope. The US is expensive, costing about 10 times as much as a SKF caliper. Finally, New regression equations appropriate to populations come from different ethnicity should be developed to determine body composition obtained from the US and SKF measurements. If the appropriate regression equations are used while determining body composition, accurate and reliable results can be obtained in the epidemiological field studies.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

1. Significant differences were found among percent body fat values of sedentary male and female university students measured by DEXA, SKF, US and BIA.

2. There were significant differences between the SKF and US measurements of sedentary male and female university students' subcutaneous fat at specified anatomical sites.

3. There were no correlations among the percent body fat values of sedentary male and female university students measured by DEXA and SKF, US and BIA.

4. New regression equations developed to predict % BF from SKF and US measurements of subcutaneous fat using DEXA as a reference method was valid and reliable.

5. New regression equation developed to predict % BF from the US measurements of subcutaneous fat using DEXA as a reference method was valid, reliable, portable, and non-invasive tool which could be used by any field investigator on obese or thin inidviduals.

6.2.Recommendations

Future research needs to more emphasis on the following areas;

1. It is recommended that a similar study should be carried out with a larger number of subjects.

2. The development of multicomponent approaches to estimate body composition such as measuring water, mineral, and protein or muscles, bone and adipose tissue.

3. Accurate estimation of muscle, bone, water, and mineral as well as fat and fat-free body may calculated by multicomponent models

4. Further researches should be designed to examine the practical multicomponent approaches to that can be used in the field.

5. The quantification of fat free body composition in various populations including athletics, prepubescent, aged and disabled individuals along with the effects of varying racial backgrounds and nutritional practices.

6. The application of various multicomponent approaches to study the influence of exercise on body composition changes and the relation of body composition to physical performance

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APPENDICES

APPENDIX A

PERSONAL INFORMATION FORM

Date of the test: ..../........./ 2003

Name and Surname: ....
Date of birth: ..../........../.............
Gender: .... Marital Status: ....
Body weight: ....kg
Body height: ....cm

Corresponding address: …..

....

Phone number: ………………….

Anthropometric Measurements

For Women

Skinfold	1	2	3	$\bar{x}$
Triceps				
Suprailiac				
Thigh				

Ultrasound	1	2	3	$\bar{x}$
Triceps				
Suprailiac				
Thigh				

For Men

Skinfold	1	2	3	$\bar{x}$
Triceps				
Suprailiac				
Thigh				

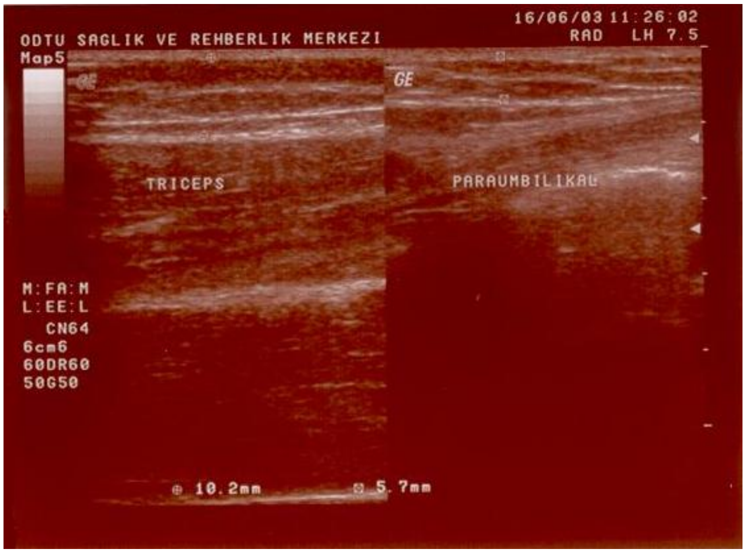
Ultrasound	1	2	3	$\bar{x}$
Triceps				
Suprailiac				
Thigh				

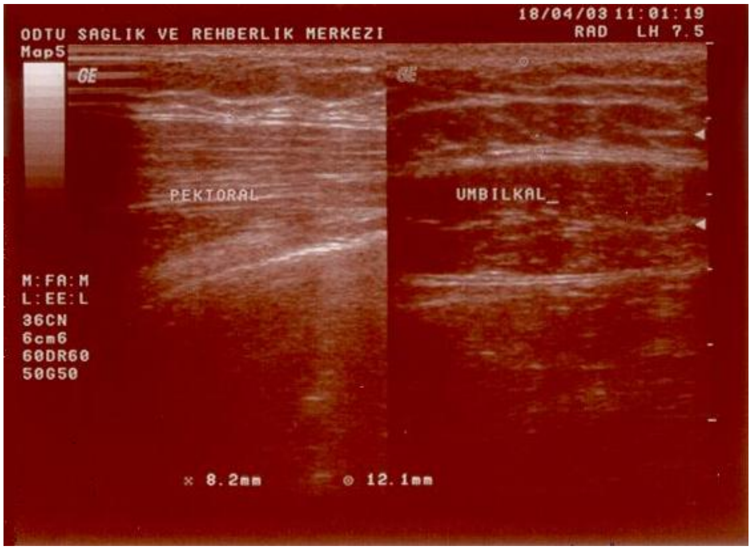
BIOELECTRICAL MEASUREMENTS

% Fat	Fat Mass

APPENDIX B

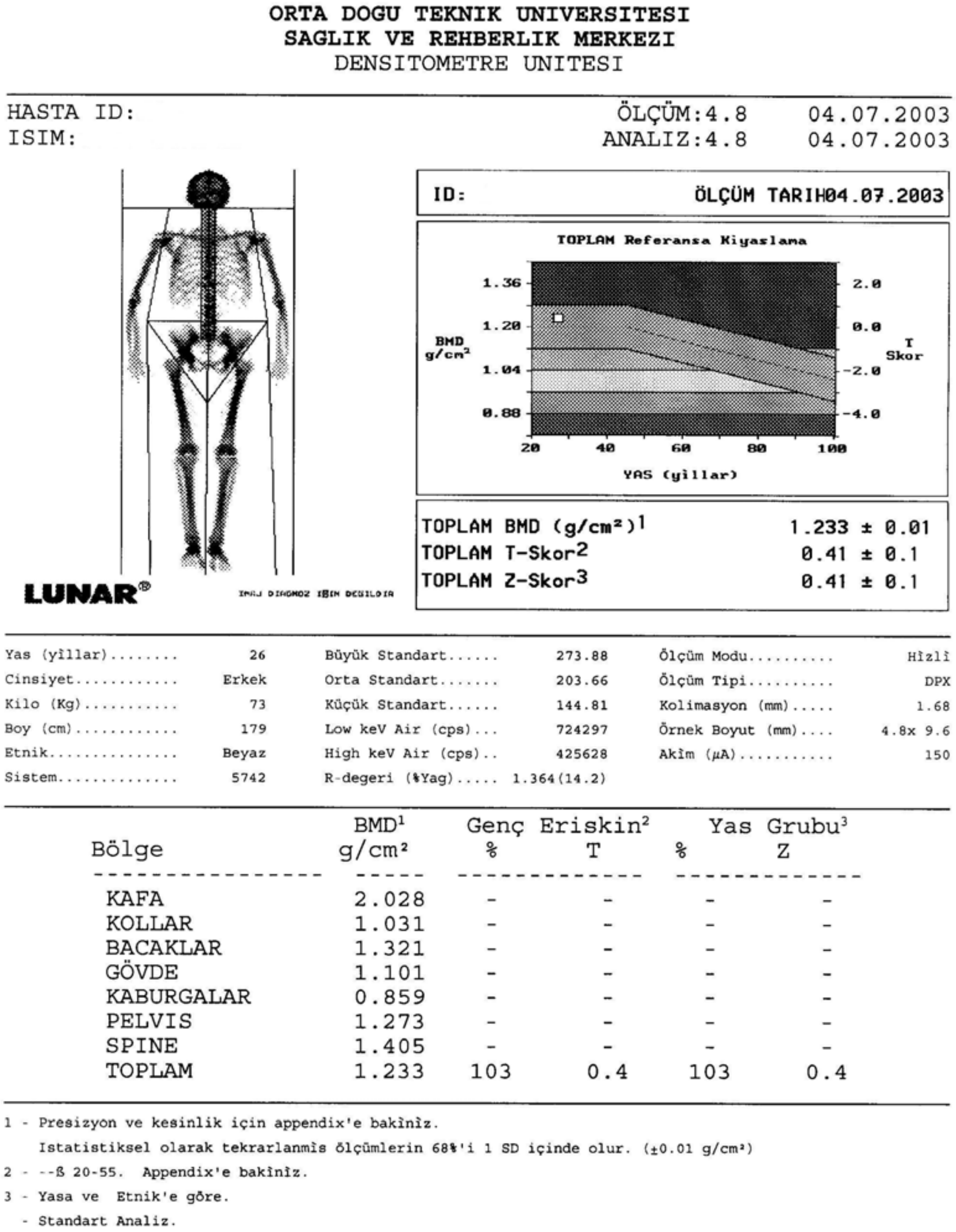
US OUTPUT





APPENDIX C

DEXA OUTPUT



ORTA DOGU TEKNIK UNIVERSITESI
SAGLIK VE REHBERLIK MERKEZI
DENSITOMETRE UNITESI

HASTA ID:		ÖLÇÜM:4.8	04.07.2003
ISIM:		ANALIZ:4.8	04.07.2003

ID: ÖLÇÜM TARIH04.07.2003

TOPLAM BMD (g/cm²)[1]	1.233 ± 0.01
TOPLAM T-Skor[2]	0.41 ± 0.1
TOPLAM Z-Skor[3]	0.41 ± 0.1

Yas (yìllar)........	26	Büyük Standart......	273.88	Ölçüm Modu..........	Hìzlì
Cinsiyet............	Erkek	Orta Standart.......	203.66	Ölçüm Tipi..........	DPX
Kilo (Kg)...........	73	Küçük Standart......	144.81	Kolimasyon (mm).....	1.68
Boy (cm)............	179	Low keV Air (cps)...	724297	Örnek Boyut (mm)....	4.8x 9.6
Etnik...............	Beyaz	High keV Air (cps)..	425628	Akìm (µA)...........	150
Sistem..............	5742	R-degeri (%Yag).....	1.364(14.2)		

Bölge	BMD[1] g/cm²	Genç Eriskin[2] %	T	Yas Grubu[3] %	Z
KAFA	2.028	-	-	-	-
KOLLAR	1.031	-	-	-	-
BACAKLAR	1.321	-	-	-	-
GÖVDE	1.101	-	-	-	-
KABURGALAR	0.859	-	-	-	-
PELVIS	1.273	-	-	-	-
SPINE	1.405	-	-	-	-
TOPLAM	1.233	103	0.4	103	0.4

1 - Presizyon ve kesinlik için appendix'e bakìnìz.
Istatistiksel olarak tekrarlanmìs ölçümlerin 68%'i 1 SD içinde olur. (±0.01 g/cm²)
2 - --ß 20-55. Appendix'e bakìnìz.
3 - Yasa ve Etnik'e gõre.
- Standart Analiz.

ORTA DOGU TEKNIK UNIVERSITESI
SAGLIK VE REHBERLIK MERKEZI
DENSITOMETRE UNITESI

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HASTA ID:                               ÖLÇÜM : 4.8    04.07.2003
ISIM:                                   ANALIZ: 4.8    04.07.2003

                        VÜCUT KOMPOZISYONU
               R    Doku    Bölge   Doku    Yag   Yagsìz  BMC
Bölge       Deger   % Yag   % Yag    (g)    (g)    (g)    (g)
----------  ------  ------- ------- ------- ------ ------ ------
SOL KOL      1.372     10.3     9.8    4332    444   3887    219
SOL BACAK    1.362     15.5    14.7   10923   1693   9230    579
SOL GÖVDE    1.364     14.7    14.2   18180   2670  15510    631
SOL TOPLAM   1.364     14.3    13.7   35162   5043  30119   1618

SAG KOL      1.374      9.3     8.8    4237    394   3843    224
SAG BACAK    1.363     14.8    14.1   10463   1553   8910    571
SAG GÖVDE    1.363     14.9    14.4   17612   2627  14984    595
SAG TOPLAM   1.365     14.1    13.5   34204   4825  29378   1599

KOLLAR       1.373      9.8     9.3    8569    837   7732    443
BACAKLAR     1.363     15.2    14.4   21386   3248  18139   1150
GÖVDE        1.363     14.8    14.3   35792   5298  30494   1226
TOPLAM       1.364     14.2    13.6   69366   9868  59497   3218

                 YARDIMCI TÜM VÜCUT SONUÇLARI**
                                           Bölge Sìnìrlandìrma
                                   Isim         Aktuel  Rölatif
                                   -----------  ------  --------
Toplam Kemik Kalsiyumu (g)..   1222Boyun             19       19
Air Points.............      15    Sol Kol          -        -
Tissue Points..........   11568    Sol Kaburga       56         -
Bone Points............    5666    Sag Kaburga       66         -
Total Points...........   24108    Sag Kol         -        -
R-Value Points.........    4767    Spine            56       56
Averaged Points........     146    Pelvis           72       72

                                   Top of Head       0
                                   Merkez            -
```

**Yardìmcì sonuçlar arastìrma içindir, klinik kullanìm için degildir.