http://www.jssm.org

JOURNAL OF SPORTS SCIENCE & MEDICINE

VOL. 2 SUPPLEMENTUM 3 2003

BODY COMPOSITION ASSESSMENT WITH SEGMENTAL MULTIFREQUENCY BIOIMPEDANCE METHOD *

Jukka A. Salmi

Department of Physiology, University of Kuopio, Kuopio, Finland

* Master thesis accepted on the 24th of September 2003 at the Faculty of Medicine of the University of Kuopio, Finland.

PREFACE AND ACKNOWLEDGMENTS

This study was carried out in the UKK Institute for Health Promotion Research in Tampere, Finland. Therefore I want to thank the people there, Katriina Kukkonen-Harjula, MD, PhD, Harri Sievänen, ScD, Patrik Borg, MSc and Mikael Fogelholm, PhD, for the possibility to for me to participate in their research project.

Especially I want to thank my supervisor's docent Harri Sievänen, ScD and docent Heikki Pekkarinen, MD, PhD for their patience during my work.

Humble thanks belong also to the reviewers of this MSc thesis professor Leo Niskanen, MD, PhD and docent Harri Sievänen, ScD.

I am very thankful to the laboratory staff at the UKK Institute for conducting all the measurements.

This study was partially supported by the companies Biospace Co. Ltd. and Mega Electronics Ltd. Also, special thanks go to Mega Electronics Ltd. and President Arto Remes for supporting the printing of this thesis.

Kuopio, September 2003

Jukka A. Salmi

There are those who seek knowledge for the sake of knowledge - that is CURIOSITY
There are those who seek knowledge to be known by others - that is VANITY
There are those who seek knowledge in order to serve - that is LOVE
St. Bernard of Clairvaux (1090 - 1153)

CONTENTS

Salmi, Jukka A. (2003) Body Composition Assessment with Segmental Multifrequency Bioimpedance Method. *Journal of Sports Science and Medicine* **2, Suppl. 3,** 1-29.

ABSTRACT

Body composition assessment is an important factor in weight management, exercise science and clinical health care. Bioelectrical impedance analysis (BIA) is widely used method for estimating body composition. The purpose of this study was to evaluate segmental multi-frequency bioimpedance method (SMFBIA) in body composition assessment with underwater weighing (UWW) and whole body dual energy x-ray absorptiometry (DXA) in healthy obese middle-aged male subjects. The measurements were carried out at the UKK Institute for Health Promotion Research in Tampere, Finland according to standard procedures of BIA, UWW and DXA. Fifty-eight (*n=58*) male subjects, aged 36-53 years, body mass index (BMI) 24.9-40.7, were studied. Of them forty (*n=40*) underwent also DXA measurement. Fat mass (FM), fat-percentage (F%) and fat free mass (FFM) were the primary outcome variables. The mean whole body FM (±SD) from UWW was 31.5 kg (±7.3). By DXA it was 29.9 kg (±8.1) and by SMFBIA it was 25.5 kg (±7.6), respectively. The Pearson correlation coefficients (*r*) were 0.91 between UWW and SMFBIA, 0.94 between DXA and SMFBIA and 0.91 between UWW and DXA, respectively. The mean segmental FFM (±SD) from DXA was 7.7 kg (±1.0) for arms, 41.7 kg (±4.6) for trunk and 21.9 kg (±2.2) for legs. By SMFBIA, it was 8.5 kg (±0.9), 31.7 kg (±2.5) and 20.3 kg (±1.6), respectively. Pearson correlation coefficients were 0.75 for arms, 0.72 for legs and 0.77 for trunk. This study demonstrates that SMFBIA is usefull method to evaluate fat mass (FM), fat free mass (FFM) and fat percentage (F%) from whole body. Moreover, SMFBIA is suitable method for assessing segmental distribution of fat free mass (FFM) compared to whole body DXA. The results of this study indicate that the SMFBIA method may be particularly advantageous in large epidemiological studies as being a simple, rapid and inexpensive method for field use of whole body and segmental body composition assessment.

KEY WORDS: Body composition, bioimpedance, multi-frequency, obesity, electrical impedance, fat mass, fat-free mass.

1. INTRODUCTION

Obesity is global (WHO, 2000) and national (Aromaa and Koskinen, 2002) epidemic worldwide. Body composition reflects the balance of physical activity and nutritional habits. Body weight alone can be very misleading. The scale cannot tell the difference between the amount of fat and muscle (Heitmann and Garby, 2002). Ageing people tend to gain fat and lose muscle without an obvious change in their weight (Baumgartner, 2000; Wang et al., 2000). And, even though we need a certain amount of fat in our bodies to insure good health, excess body fat has been found to increase the risk of diseases such as type II diabetes (Smith and Ravussin, 2002), cardiovascular disease (Rashid et al., 2003) and cancer (Calle et al., 2003). On the other hand, too little body fat can also pose a number of health risks, especially for women.

When assessing the overweight or obesity the self-reported measures can mislead the results as well. The results from self-reported measures may lead to around 30% misclassification of body composition (Wang et al., 2002). Therefore objective body composition assessments are essential for the whole healthcare field.

Only by accurately analysing body composition, you will learn the amount of fat and lean tissue that makes up your weight, enabling sensible decisions regarding nutrition and exercise programs. Body composition assessment is an advanced method to investigate the status of the human body.

Bioelectrical impedance analysis (BIA) is widely used method for estimating body composition. Wide range of measuring apparata exists for field and clinical use. BIA and its accuracy are dependent on apparatus and valid choice of prediction equation used (Heitmann, 1994; Ellis, 2001).

This thesis describes body composition assessment principles and specific methods. Furthermore, the purpose of this thesis is to compare the method of segmental multi-frequency bioimpedance analysis (SMFBIA) to underwater weighing (UWW) and dual energy x-ray absorptiometry (DXA).

2. BODY COMPOSITION

Body composition analysis can be classified according to several models, depending on the

purpose or analysis methods and devices available. These include mainly atomic model, molecular model, cellular model and tissue-system model and of course the whole body model as well (Figure 1, Table 1) (Pietrobelli et al., 2001). Most of these models are based on the constant relationship between different components inside the model. Body composition models with most relevant measurement methods are presented at the end of this chapter (Table 2).

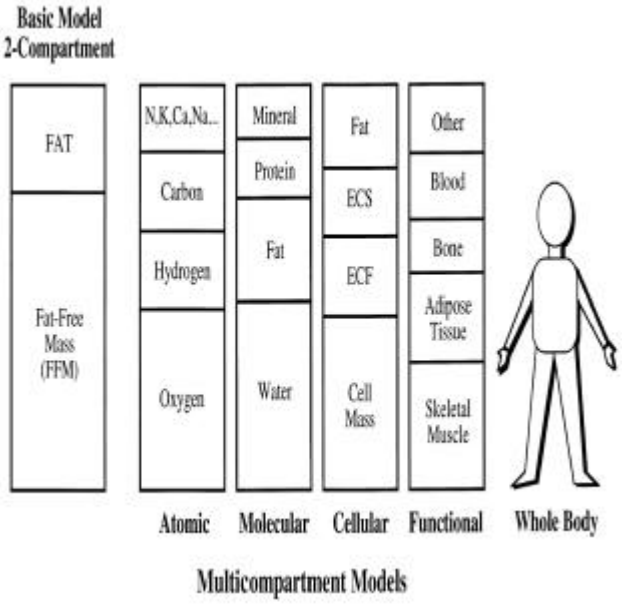


Figure 1. Body composition models (Adapted from Ellis, 2000).

2.1. Atomic model

About 50 of the 106 elements found in nature are also found in the human body. The atomic level usually includes 11 main elements: oxygen (O), carbon (C), hydrogen (H), nitrogen (N), calcium (Ca), phosphorus (P), potassium (K), sulphur (S), sodium (Na), chlorine (Cl), and magnesium (Mg) (Table 1). Four of those elements; O, C, H, and N account for over 95% of body mass. With additional seven; Na, K, P, Cl, Ca, Mg, and S we are talking about over 99% of total body mass (Wang et al., 1992). All these main elements are measurable in vivo by neutron activation analysis (NAA) combined with whole body ^{40}K counting (see chapter 3.2.6.) (Pierson et al., 1990). In this model it is therefore possible to reconstruct the molecular level model from human body (Pietrobelli et al., 2001).

2.2. Molecular model

The molecular model (Figure 1) is the most studied model in the field of body composition research. Many biological processes can be related to molecular level components and hence there is a large research interest in assessing these main tissues. The classical two-component (2-C) model consisting of fat (FM) and fat-free mass (FFM) (Figure 2) is a molecular level model (Siri, 1956; Brozek, 1966). Concern of the validity of the two-component model in subjects who vary in age, gender and race led to the development of molecular multi-component models.

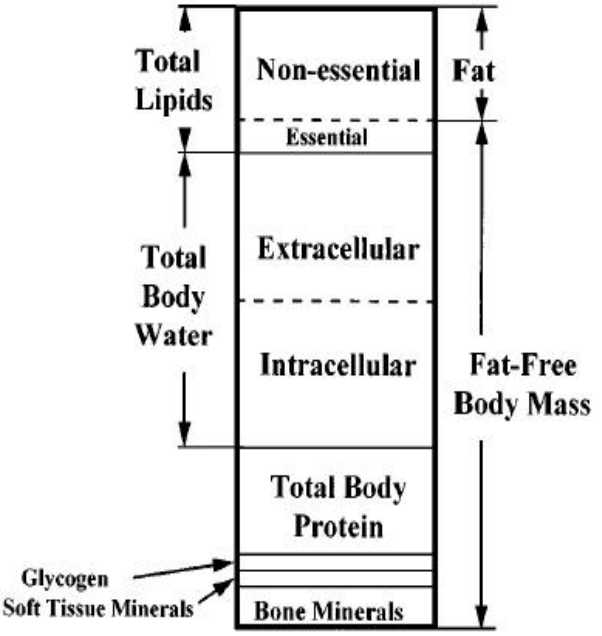


Figure 2. Molecular level components (Adapted from Heymsfield et al., 1997).

2.3. Cellular model

The human body cellular model consists from three main components including cells, extracellular fluids, and extracellular solids (Table 1). Further research has proposed that including body cell mass (BCM) to the cellular model makes it more functional. Today the most accepted cellular model is therefore BW = FM + extracellular fluids + extracellular solids + BCM. BCM is assessable by total body potassium measurement. Extracellular fluids are measurable by dilution methods or by a combination of TBW and total body potassium. Extracellular solids can be estimated from constant relationship between BMC and extracellular solids measured by DXA. Cellular model have been found to be important in physiological evaluations since cells constitute the functional biological element of human body (Heymsfield et al., 1997; Pietrobelli et al., 2001).

Table 1. Examples of body composition models (Modified from Heymsfield et al., 1997). All units are in kilograms.

Level/ Level	Model
Atomic/Atomic	TBS = 0.062 x TBN
Atomic/Atomic	TBP = 0.456 x TBCa + 0.555 x TBK
Atomic/Molecular	TBCa = 0.364 x MO
Atomic/Molecular	TBN = 0.16 x protein
Atomic/Molecular	TBK = 0.00266 x fat-free body mass
Atomic/Molecular	Carbon = 0.774 x fat
Atomic/Molecular	TBS = 0.010 x protein
Atomic/Molecular	TBK = 0.00469 x body cell mass
Atomic/Whole body	TBH = 0.10 x BW
Atomic/Molecular	TBW = 0.732 x fat-free body mass
Atomic/Molecular	Glycogen = 0.044 x protein
Whole body/Atomic	BW = O + C + H + N + Ca +P + S + K + Na +Cl + Mg
Atomic/Molecular	BW = lipids + water + protein + MO + MS + glycogen
Atomic/Molecular	BW = fat + fat-free body mass
Whole body/Cellular	BW = cell mass + extracellular fluids + extracellular solids
Whole body/Tissue-System	BW = adipose tissue + skeletal muscle + bone + viscera + blood + R
Whole body/ Whole body	BW = head + neck + trunk + lower extremities + upper extremities

Abbreviations: TB = Total body, MO = Bone mineral, BW = Body weight, MS = Soft tissue minerals, R = Residues.

2.4. Tissue-System model

The main tissue-system model components are adipose tissue, skeletal muscle, bone, visceral organs, and brain (Table 1). Adipose tissue is further divided into subcutaneous, visceral, yellow marrow, and interstitial fat components (Wang et al., 1992). Until recently, anthropometrical methods have been main methods for assessing body composition according to tissue-system model. After developing interpretation models, also computerized tomography (CT) and magnetic resonance imaging (MRI) have shown their possibilities. There are extensive validation studies for both CT and MRI, which include phantoms and human and animal cadavers (Heymsfield et al., 1979a; Heymsfield et al., 1979b; Rossner et al., 1990; Ross et al., 1991; Ross et al., 1992; Abate et al., 1994). Hence, CT and MRI are potential candidates for further reference methods in body composition method validation studies for field methods.

2.5. Multi-component models

Multi-component models are usually a mixture of different body composition models described previously. The purpose of multi-component methods is to improve the accuracy of the body composition assessment and provide more reliable results, especially in scientific research (Ellis, 2000).

The classical two-component (2-C) model assessing of fat and fat-free mass (compartments) by measuring body density (Siri, 1956; Brozek, 1966) is probably the most studied and used reference method for newer body composition assessment methods.

To reduce the limitations in 2-C model it was logical to expand to three-component (3-C) configuration. Typical approach is to include total body water (TBW) to 2-C model, usually with dilution method (see chapter 3.2.). Unfortunately, this does not improve the method too much. To the subjects with unstable protein and/or mineral condition the estimated values for solids compartment will be incorrect. That leads to inaccurate body fat estimation as well (Ellis, 2000).

Natural expand to four-component (4-C) model is to add protein (NAA, see chapter 3.6.) or mineral measurement (DXA, see chapter 3.3.) to 3-C model. In 4-C model the body is divided into fat, protein, fluid, and mineral (Figure 3.). These factors are important in clinical use and are helpful in providing nutritional information (e.g. BCM, soft lean mass). The 4-C model can provide more thorough information and efficient classification in health care field.

The six-component (6-C) model is probably the latest and most challenging model of all. It consists from TBW, N, Ca, K, Na, and Cl, where TBW is measured by dilution method (see chapter 3.2.) and remainder by NAA (see chapter 3.6.) (Wang et al., 1998; Wang et al., 2002).

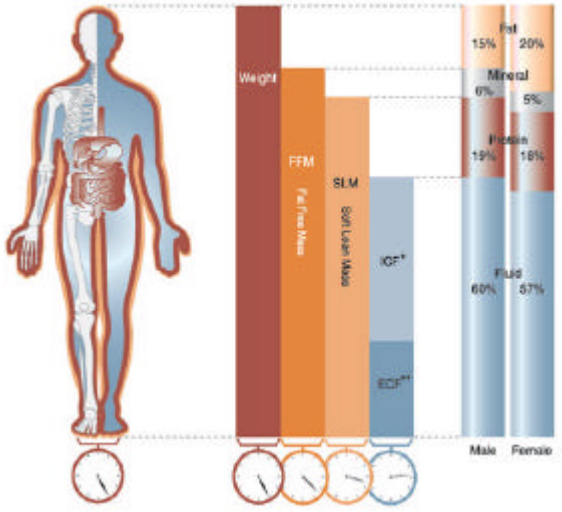


Figure 3. Schematic diagram from four-component model with gender differences. (Adapted from. Biospace Co. Ltd. web site http://www.biospace.co.kr). Weight = Fat Free Mass + Fat; Fat Free Mass = Soft Lean Mass + Mineral; Soft Lean Mass = Water + Protein; Water = ECF (Extra Cellular Fluid) + ICF (Intra Cellular Fluid).

3. METHODS OF BODY COMPOSITION ASSESSMENT

3.1. Underwater weighing

The measurement of body density is often referred to as a golden standard for body composition assessment; despite it is only a 2C model. The most commonly used method for assessing total body density is UWW, which requires the subject to be submerged in water. Then the residual lung volume is measured, the most commonly used method is oxygen dilution with a closed-circuit spirometer system. The volume of water displaced or the weight of the subject underwater, compared to the subject's normal weight, are used to calculate the density of the whole body. The result is then corrected by residual lung volume (Siri, 1956; Brozek, 1966).

The UWW methods were developed mainly as a means to measure body volume to assess body fatness (FM and/or F%). Even if the body weight and volume could be measured without error, there would still be considerable uncertainty regarding the individual's body fatness estimate due to normal variations in body hydration, protein, and mineral content. It has been estimated that the total error for body fatness is ~3-4% of body weight for individuals (Heymsfield et al., 1989). Thus, it has been recommended that without correction for variation in the water and mineral content of FFM, densitometry should not be used as a reference method for heterogenic population.

3.2. Dilution method

Dilution method with labelled water is an accurate method for total body water (TBW) measurement. It is performed by introducing orally or intravenously a certain substance (a tracer) like deuterium oxide (D^2O), oxygen-18, or tritium (radioactive; not recommended) into the human body, and then collecting two body fluid samples (blood, urine, or saliva),one before introducing the tracer and second after an equilibration time of ~2-4 hours. Then the substance (tracer) is equilibrated with water in the subject's body, and the density of the substance is analyzed. Dilution takes many hours of measurement and cannot be measured repeatedly. However, because it is rather accurate, it is used to measure body water in research purposes (Ellis, 2000).

3.3. Dual energy x-ray absorptiometry

Dual energy X-ray absorptiometry (DXA) is the most used imaging method of body composition assessment. It is mostly used for bone density assessment for osteoporosis diagnostic purposes and clinical bone research, but also whole body composition assessment by DXA has become a popular method. Hence, DXA is available in most of the bigger hospitals and research centers.

When an X-ray or photon source is placed on one side of an object, the intensity of the beam on the opposite side of the object is related to its thickness, density, and chemical composition. This attenuation phenomenon is also dependent on the energy of the incident photons and is dominated by two principles at low energies: the photoelectric effect and Compton scattering. The attenuation response is nonlinear, such that for a homogeneous material, it can be described by the exponential equation. If the absorber is composed of two or more materials, then the composite is the weight sum of the individual mass attenuation coefficients, each weighted for its fractional contribution to the totalmass (Heymsfield et al., 1997).

The attenuation through bone, lean tissue, and fat is different, reflecting their differences in densities and chemical composition. With increasing photon energy, the differences in the attenuation properties for these tissues decrease. Thus, if the relative intensity of the transmitted beam can be measured, and the mass attenuation coefficients are accurately known, estimates of the bone mass and overlaying soft tissue mass can be calculated. This 2C model is also used when the beam passes through body regions without bone. In this case, the appropriate attenuation

Table 2. Body composition models and some relevant measurement methods. (Modified from Heymsfield et al., 1997).

Level	Recently developed or Improved methods	Other methods
Atomic	Neutron activation analysis	Whole-body ^{40}K counting
		Tracer dilution
Molecular	Bioimpedance analysis	Underwater weighing
	Dual energy X-ray absorptiometry	Infrared interactance
	Multi-component models	Tracer and gas dilution
Cellular		Tracer dilution
Tissue-System	Computerized axial tomography	Ultrasound
	Magnetic resonance imaging	24-h urinary creatinine and 3-methyl histidine excretion
Whole body		Anthropometry

coefficients are those for fat and lean tissues, respectively (Heymsfield et al., 1997).

It should be evident that DXA is composed of two separate sets of equations, each used to describe a 2-C model. Dual-energy X-ray absorptiometry does not provide three independent measurements, even though three body composition values [bone mineral content (BMC), lean tissue mass (LTM), and fat mass (FM)] are reported (Figure 4.). To accomplish this, the manufacturers must assume that the composition of the soft tissue layer overlaying bone has the same fat-to-lean ratio as that for non-bone pixels in the same scan region. In the case of the whole body scan, ~40-45% of the pixels are classified as containing bone. The remaining pixels are used to estimate the body's fat-to-lean ratio; this value is applied to the soft tissue component in the adjacent bone pixels. Thus, the relative lean-to-fat composition of the total soft tissue mass is based on sampling only one-half of the whole body (Mazess et al., 1990).

Some investigators have expressed their concern about measurement bias related to the impact of a significant change in the hydration of the lean tissues. The latter concern, however, has recently been theoretically shown not to significantly alter the estimates for the bone, lean, or fat mass (Pietrobelli et al., 1998b).

3.4. Computed tomography

Computed tomography (CT) technique uses X-rays that are collimated to provide a fan-shaped beam that is passed through the body, while an array of detectors is on the opposite side of the subject to detect the transmitted radiation. The X-ray source and detector assembly are rotated as a single unit around the subject covering a full 360°. Alternatively, some devices have a full circle of detectors, and only the X-ray source is rotated. At each degree of rotation, the transmitted intensity is recorded for each detector, providing information about the internal structures along that beam circle (Baumgartner et al., 1988).

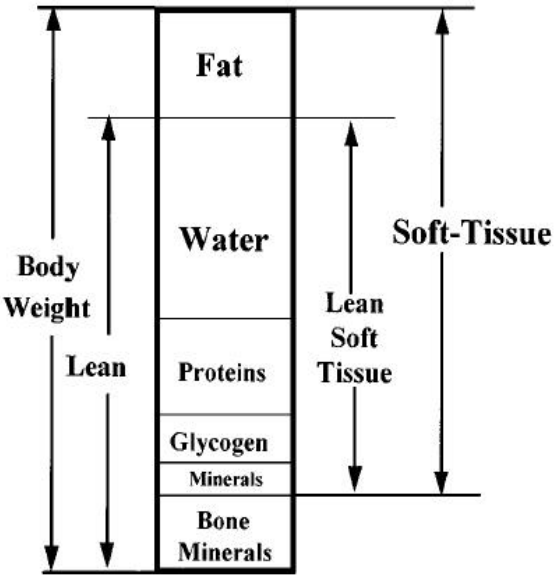


Figure 4. DXA molecular level model. (Adapted from Heymsfield et al., 1997).

Many reconstruction algorithms have been demonstrated to produce a cross-sectional image of the body region. This basic anatomical image contains information of the tissue density at each pixel. This information together with the anatomical location of the pixel in the image can be used to identify it as adipose, muscle, skin, visceral, or bone tissue. Reconstruction of total body mass and separate organ masses based on scans along the length of the body at 10-cm intervals has been shown to have excellent accuracy (<1% error) and precision (<1%). These reconstructed CT images can be assigned to level 4 or tissue systems level of the multi-component model. The CT images can also be

used to separate the total adipose tissue mass into its subcutaneous and visceral components, or the lean tissues into skeletal muscle and visceral or organ mass. Likewise, bone can be identified as cortical or trabecular in nature on the basis of density (Baumgartner et al., 1988; Rossner et al., 1990; Ross et al., 1991).

The major disadvantage with CT is the radiation dose required per slice for scanning. However, if the pixel resolution required for routine CT scans can be reduced, then the dose can be significantly reduced. Recent studies have shown that a dose can be reduced to 1/25 that of a routine clinical CT scan dose (Baumgartner et al., 1988; Rossner et al., 1990; Ross et al., 1991; Goodpaster et al., 2000).

3.5. Magnetic resonance imaging

The strength of the earth's magnetic fields is very weak, despite that, atoms and molecules in the body are in random orientations. However, when the body is placed in a strong magnetic field, some nuclei tend to align with or against the magnetic field. Hydrogen protons (^{1}H), in particular, have a high affinity for alignment with the magnetic field. Some other atoms (^{13}C, ^{19}F, ^{23}Na, ^{31}P, and ^{39}K) also show similar properties, but at a lower response than for hydrogen atoms. Although only a small percentage of nuclei will be aligned, the number is sufficient to detect a change in their orientation when the magnetic field is removed or altered.

The frequency at which nuclei for each element will flip is called the Larmor frequency. When radiofrequency (RF) energy, at the Larmor frequency, is applied perpendicular to the direction of the magnetic field, the nuclei will absorb this energy and change its alignment. When the RF field is turned off, the nuclei will lose their alignment and release the stored energy. The intensity of this signal can be used to measure the number of hydrogen nuclei of the tissue. This process can be repeated at each position along the length of body until the whole body is mapped and cross-sectional images at each slice can be generated. Magnetic resonance imaging (MRI) is successful because hydrogen, found mainly in water, is one of the most abundant non-bound elements in the body. For other elements, their concentrations in the body are lower and the Larmor frequency changes, thus requiring an increased magnetic field strength if imaging is to be considered (Abate et al., 1994; Mitsiopoulos et al., 1998).

If the hydrogen densities of adipose and lean tissues were markedly different, then it would be possible to develop images based solely on their number of nuclei. To see the contrast between lean and fat tissues, a second feature of the nuclei, called relaxation time (*T1*), is used. This is the time it takes for the nuclei to release the RF-induced energy and return to a random configuration. The *T1* for protons in fat is much shorter than that for protons in water. This contrast can be maximized by adjusting the time interval of the RF pulse and the time to detect the induced signal. The total process is often referred to as a pulse sequence or spin-echo sequence (Ross et al., 1991; Baumgartner et al., 1992; Ross et al., 1992; Abate et al., 1994; Mitsiopoulos et al., 1998; Ross et al., 2000).

3.6. Neutron activation analysis

A substantial paradigm change in the study of body composition occurred with the development of in vivo neutron activation analysis (NAA) technique. These procedures allowed for the direct elemental analysis of the living human body. Alternate body composition techniques such as CT, MRI, DXA, BIA, and dilution method provide estimation related to tissue density or volume, but not chemical content. For this reason, the multi-component models based on NAA have become the most preferred reference for evaluation and/or calibration of the alternate methods. Virtually all the major elements of the body can be assayed in vivo: hydrogen, oxygen, carbon, nitrogen, calcium, phosphorus, sodium, chlorine, and potassium (via ^{40}K counting). Accuracy of NAA is at least as good as that obtained using classical "wet chemistry" techniques. Although NAA facilities have been in use for more than 30 years, a direct comparison of results between two systems has been reported only recently. A major disadvantage of the NAA technique is that most of the dose is delivered to the body without the production of a useful signal. Probably one of the major concerns restraining a more general use of NAA technique is the association to radiation exposure. (Beddoe and Hill, 1985; Pierson et al., 1990; Wang et al., 1993; Morgan, 2000; Wang et al., 2002).

3.7. Bioelectric impedance analysis

The property of tissues, and the whole body, to conduct an electric current has been known for more than a hundred years. Electricity flows through tissues that contain water in the human body. When electric signals are sent to our body, electric currents flows through the most conductive tissue. Depending on the amount of body water, the width of the passage of electricity flows is determined. The aqueous tissues of the body, due to their dissolved electrolytes, are the major pathways of an electrical

current, whereas body fat and bone have relatively poor conductive properties. Bioelectric impedance analysis (BIA) measures body water based on this principle.

For the BIA measurement, a low alternating current is conducted through the outer pair of electrodes, while the inner pair of electrodes from which the impedance is measured measure the drop of voltage. To convert this information to a volume estimate, two basic assumptions are used. Firstly, the body can be modelled as a cylindrical conductor with its length proportional to the subject's height (Ht). Secondly, the reactance component (X) contributing to the body's impedance (Z) is small, such that the resistance component (R) can be considered equivalent to body impedance. When these two assumptions are combined, it can be shown that the conducting volume is proportional to the term Ht^2/R, called the impedance index. In the classical BIA method, it was hypothesized that a human body is a cylinder like the figure below (Figure 5.), and BIA measures total body water (TBW). The amount of water is equal to the volume of the cylinder.

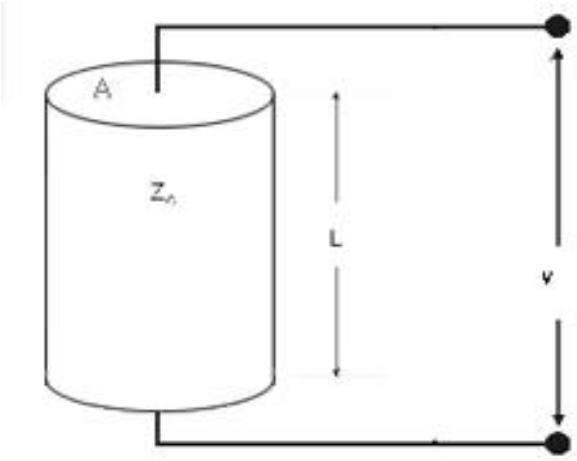


Figure 5. Model of human body or body segment as cylinder with length, area and impedance describing body water volume.

With BIA, the cell membrane and fat tissue show high impedance with electric current. Electrolytes dissolved in the water of lean body tissue provide good conductivity.

Since BIA is estimating the water content of the body compartments, the stable state of tissue hydration is crucial for the reliable BIA measurement. Furthermore, BIA principle implies that the meal and the weight of food in intestines (Fogelholm et al., 1993; Slinde and Rossander-Hulthen, 2001), clothing, skin temperature, and blood flow (Caton et al., 1988; Liang and Norris, 1993; Gudivaka et al., 1996; Liang et al., 2000), and so forth affects the accuracy of measurement.

From total body water, body fat mass can be estimated. After age, height and weight are taken into account the body water is estimated. Lean body mass is in proportion to total body water. The estimation is based on a constant relationship of 72.3% water in LBM (Wang et al., 1999). When LBM is subtracted from weight, body fat mass is calculated, 2-C model. Body fat mass is typically calculated with a regression analysis equation directly from the impedance index.

The bioelectrical impedance method is easy to use and can be readily repeated. At present, BIA is probably the most frequently used method, due mainly to the relatively inexpensive cost of the basic instrumentation, its ease of operation, and its portability.

3.7.1. Single-frequency bioimpedance analysis

Traditionally the BIA measurements are performed using four electrodes: usually two are attached at the wrist and two at the ankle and measurement is performed in supine position. Typically a single frequency current of 50 kHz is used. At 50 kHz the body's impedance has both resistive and reactive components. The reactive component is assumed to be related to the portion of the current that passes through cells, which act like capacitors that shift the voltage, and current out of phase.

3.7.2. Multi-frequency bioimpedance analysis

Multi-frequency bioelectrical impedance analysis (MFBIA) or sometimes bioelectrical impedance spectroscopy (BIS) has been mainly developed for improving the accuracy of BIA and also for assessing the ratio of intracellular water (ICW) and extracellular water (ECW). The technique is based on the hypothesis that lower frequencies ($\leq$50 kHz) flows within extracellular compartment, whereas higher frequencies ($\geq$200 kHz) could pass trough cell membrane and hence measure the intracellular space (Figure 6.). Moreover, when the frequency of the electrical signal is changed, the direction of the electricity can be changed. Using this principle, intracellular fluid and extracellular fluid can be distinguished and measured separately. Normally, MFBIA is used at frequencies from 1 kHz ~ 1 MHz (Cha et al., 1995; Ellis et al., 1999b; Gudivaka et al., 1999; Tagliabue et al., 2001).

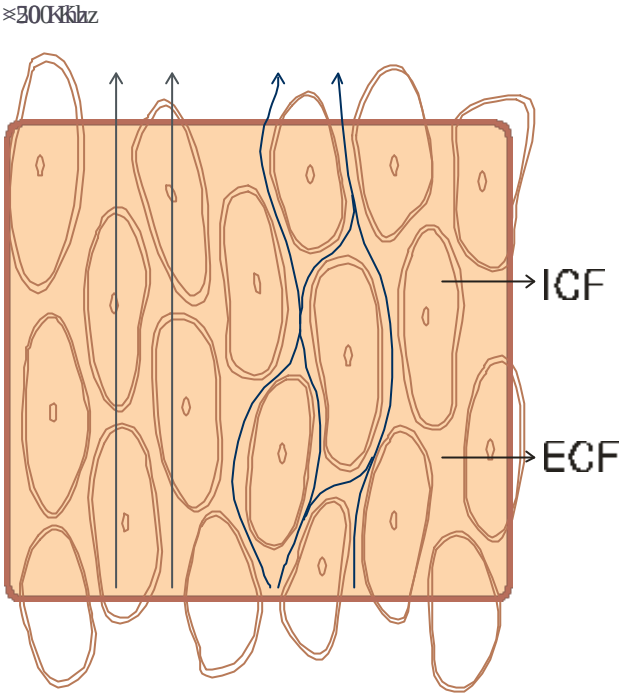


Figure 6. Illustration on MFBIA model (Adapted from Biospace Co. Ltd. Technology leaflet).

3.7.3. Segmental bioimpedance analysis

Segmental analysis of body composition can be understood in two different bases. Firstly, by measuring a certain body segment and thereafter from the result assessing the total body composition. Secondly, by measuring all different body segments separately one could improve the accuracy of total body composition assessment. (Figure 7.) Typical model for segmental assessment by BIA, also known from DXA models, is to divide body as upper and lower extremities and trunk. This is the segmental model taken in consideration hereafter in this thesis (Chumlea et al., 1988; Chumlea et al., 1990; Organ et al., 1994).

3.7.4. Segmental multi-frequency bioimpedance analysis

By combining segmental and multi-frequency bioimpedance methods there could be found some benefits in accuracy and possibility of determining body shape variation in individuals. Moreover, the need for some background information such as age or gender for the equation used for BIA, body composition assessment may become less dominant in multiple regression analysis. Pietrobelli and Tagliabue with groups have reported advances in appendicular LBM assessment by SMFBIA (Pietrobelli et al., 1998a; Tagliabue et al., 2001). While Bedogni and Cha have described TBW assessment advances by SMFBIA (Cha et al., 1995; Bedogni et al., 2002). This method is further studied in this thesis.

3.8. Air displacement plethysmography

In recent years, the UWW technique has begun to be replaced by air-displacement plethysmography, where the subject is immersed not in water but in a closed air-filled chamber.

The system consists of two chambers: one for the subject and the other serving as a reference volume (Figure 8.). With the subject in one chamber, the door is closed and sealed, the pressure increased slightly, and a diaphragm, separating the two chambers, is oscillated to slightly alter the volumes. The classic relationship of pressure versus volume, at a fixed temperature, is used to solve for the volume of the subject chamber.

An advantage of this technique compared with the UWW measurement is that the subject does not have to be submerged in water; however, all of the technical limitations related to the true volume that were noted for the UWW method remain. These instruments presently are designed for adults and will require significant modifications and improvements if the technique is to become useful for monitoring smaller subjects, including infants (Dempster and Aitkens, 1995; McCrory et al., 1995; McCrory et al., 1998; Levenhagen et al., 1999).

3.9. Skinfold thickness

When squeezing the triceps of an obese person, we can perceive that it is thicker than that of a muscular person. This is because the subcutaneous fat is thicker. Considering the fact that over 50% of body fat is under the skin, thickness of subcutaneous fat in the triceps, thighs and abdomen can be measured with a round shaped ruler. The skinfold measurement (subcutaneous fat thickness measuring method) is used for calculating total body fat, by measuring thickness of subcutaneous fat. Skinfold measurement is done under the assumption that 50% of subcutaneous fat is body fat. If the body fat distribution varies within individuals, it affects the accuracy and the measurement results. Therefore, reliability of this method is low (Wagner and Heyward, 1999).

3.10. Near-infrared measurement

When an object is exposed to infrared light, the object absorbs or reflects the light according to its chemical structural properties. All organic materials (i.e. fat or protein) absorb light in unique portions of the spectrum. Futrex, Inc., MD, USA has developed a device to analyze human body composition by this

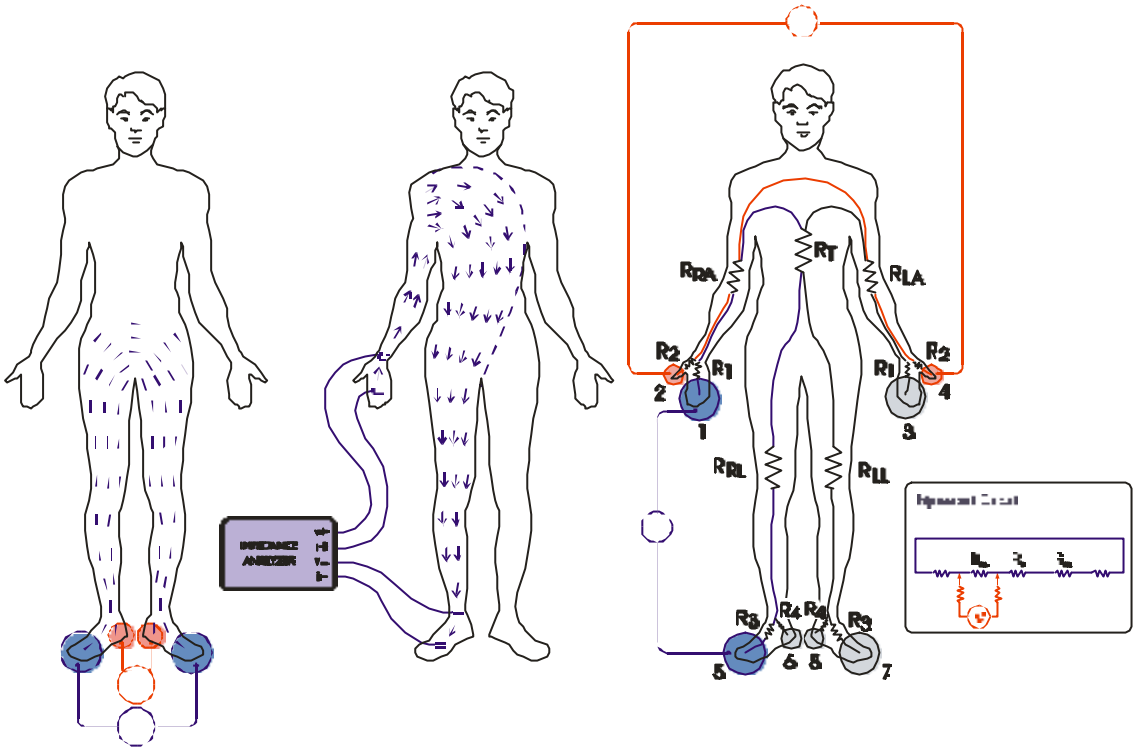


Figure 7. Examples of segmental BIA models (Adapted from Biospace Co. Ltd. Technology leaflet).

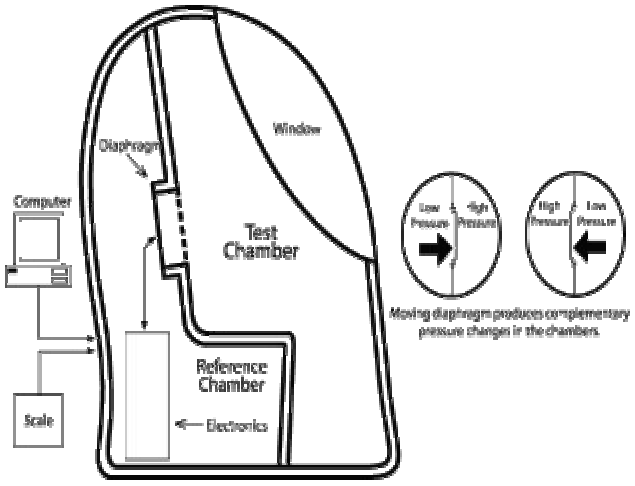


Figure 8. Basic principal of the air displacement plethysmography (Adapted from Life Measurement, Inc. web site: http://www.bodpod.com/index.php).

technique. It estimates body composition by analyzing the spectrum of near infrared light reflected from the skin and underlying tissue (Conway et al., 1984; Elia et al., 1990; McLean and Skinner, 1992).

The Futrex device emits near infrared light at very precise frequencies (938 nm and 948 nm) into body-frequencies at which a body fat absorbs the light and the lean body mass reflect the light. In essence, it is measuring how much light is emitted from the light wand and how much light is reflected back into the light wand. This measurement provides an estimation of the distribution between the body fat and lean body mass (Conway et al., 1984; Elia et al., 1990; McLean and Skinner, 1992).

Infrared measurements from the biceps have been the primary site shown to correlate best with a criterion method However, it overestimates the fat of a thin person and underestimates the fat in an obese person compared to underwater weighing, skinfold measurement or BIA (Conway et al., 1984; Elia et al., 1990; McLean and Skinner, 1992).

3.11. Circumferences and other measurement methods

It is generally accepted that not only excess weight, but also the distribution of body fat, is associated with several diseases. In particular, abdominal obesity, indicated by a high waist circumference, waist-to-hip ratio (WHR), and abdominal sagittal measurement have been shown to predict diseases like hypertension, coronary heart disease (CHD), non-insulin dependent diabetes mellitus (NIDDM) and stroke, and these measurements have been shown to correlate with other cardiovascular risk factors and increase mortality independent of body mass. It has been suggested that this excess risk with central obesity is primarily due to metabolic

alterations caused by intra-abdominal fat deposits (Molarius and Seidell, 1998). Body mass index (BMI) is also an independent marker of body composition and therefore available method for assessing obesity and overweight related diseases (Lahti-Koski, 2001).

Table 3. Classification of WC by WHO. Source: (WHO, 2000)

Classification of risks by WC	Female	Male
Low risk	≤79 cm	≤93 cm
Increased risk	80-87 cm	94-101 cm
Substantially increased risk	≥88 cm	≥102 cm

3.11.1. Waist circumference

Waist circumference (WC) is a very strong predictor for abdominal obesity related diseases. The recommended procedure for the measurement of the WC is following: Subject standing with light garments and waist is measured at the level midway between the lower rib margin and the iliac crest, with the participant breathing out gently. The measurement is usually rounded to the nearest 0.5 cm. The cut-off points of WC are classified and recommended by WHO (WHO, 2000; Janssen et al., 2002). Recent evidence suggests that WC alone may be a better indicator of abdominal visceral fat (Rankinen et al., 1999) and a predictor of abdominal obesity related diseases (Molarius and Seidell, 1998; Molarius et al., 1999a; Molarius et al., 1999b; Nordhamn et al., 2000) and mortality (Visscher et al., 2001) than WHR or BMI.

3.11.2. Waist-hip ratio

Waist-hip ratio (WHR) is probably the most used method for assessing abdominal fat distribution so far. The recommended procedure for the measurement of the WHR is following: Subject standing with light garments waist is measured at the level midway between the lower rib margin and the iliac crest, with the participant breathing out gently. Hip is measured as the maximum circumference over the buttocks. Both measurements are rounded to the nearest 0.5 cm. The WHR is calculated by dividing waist circumference with hip circumference. The suggested cut-off points of WHR are varying between 0.80 and 0.90 for female and 0.94 and 1.00 for male, respectively (Molarius and Seidell, 1998; Lahti-Koski, 2001).

3.11.3. Sagittal abdominal diameter

Sagittal abdominal diameter (SAD) is a less used assessment method among anthropometrical methods. Despite, it has been studied to be one of the strongest predictors of overweight related diseases. Besides, SAD has one of the highest reliability among similar measurements and it is rather easy to perform with inexpensive ruler. SAD is measured with the subject in a supine position. It can be done both with the legs stretched and bent but legs bent have showed some better confidence to predictability. The perpendicular distance between the plane of support and the highest point of the abdomen is measured and read to the nearest 1 mm. (Nordhamn et al., 2000; Ohrvall et al., 2000) The major problem with SAD is that there is a lack of cut-off values. For these reasons, further research about SAD should be conducted very soon.

Table 4. Classification of BMI by WHO (Adapted from Seidell and Flegal, 1997). Source: (WHO, 2000).

Classification	BMI ($kg \cdot m^{-2}$)	Population description
Underweight	<18.5	Thin
Normal range	18.5-24.9	Normal, healthy, acceptable weight
Overweight	≤25	
Pre-obese	25-29.9	Overweight
Obese class I	30.0-34.9	Obesity
Obese class II	35.0-39.9	Obesity
Obese class III	≥40	Morbid obesity

3.11.4. Body mass index

Body mass index (BMI) is probably the most used assessment index of obesity. BMI is calculated by dividing weight (kg) with squared height (m). It is important to understand that BMI is not a measure ($kg \cdot m^{-2}$) it is just an index. The biggest source of error comes from subjects with high muscle mass in other words BMI fails to distinguish between lean body mass and fat (Lahti-Koski, 2001). The classification of body composition by BMI, recommended by WHO, is presented in Table 4.

4. AIMS OF THE STUDY

The objective of this study was to evaluate segmental multi-frequency bioimpedance method (SMFBIA) in body composition assessment. The aim was to cross-validate SMFBIA against under water weighing (UWW) and whole body dual energy x-ray absorptiometry (DXA).

1. The primary outcome was to compare fat mass (FM), fat free mass (FFM) and fat percentage (F%) from all three methods.
2. The secondary objective was to compare segmental dstribution of FFM by SMFBIA and whole body DXA.

5. METHODS

The measurements were carried out at the UKK Institute for Health Promotion Research in Tampere, Finland between March 27th - June 15th, 2000 according to standard procedures of SMFBIA, UWW and DXA.

In addition to the measurement of body composition using bioimpedance analysis, UWW and whole body DXA the measurements performed recording of age, weight, height and waist-hip ratio (WHR) as well.

The study was approved by an independent Research Ethical Committee of UKK Institute. Written informed consent was obtained from the participants.

5.1. Subjects

The study subjects were recruited from a sub-population of a weight loss maintenance study (Borg et al., 2002). Fifty-eight (*n=58)* male subjects were studied. Only forty (*n=40*) of them underwent also DXA measurement because of size limitations of DXA device. Therefore, only those forty subjects were taken in account at the final analysis. The final study subjects ranged 36-53 years in age and 24.9-40.7 in BMI. Subject characteristics are presented in Table 5.

5.2. Underwater weighing

Body weight was measured with a high-precision scale (F150S-D2, Sartorius, Goettingen, Germany), with the subjects wearing only their underwear. Residual lung volume was measured two to four times before underwater weighing using the helium-dilution method (Pulmonet III, Sensor Medics BV, Bilthoven, the Netherlands) while the subject was in a sitting position.

The subject's body density was assessed by underwater weighing, after full exhalation (presumably at residual lung volume) in a sitting position submerged to the chest. Eight to ten submerge trials was performed. (Fogelholm et al., 1996; Fogelholm et al., 1997).

Body composition was calculated from the body density by a two-component model in which the body was divided into fat and fat-free compartments with assumed densities of 0.9 and 1.1 $g \cdot cm^{-3}$, respectively (Siri, 1956).

5.3. Dual energy x-ray absorptiometry

Total body scan was carried out using whole body dual-energy X-ray absorptiometry (DXA) (Norland XR-26; Norland, Fort Atkinson, WI, USA) according to standard procedures. Total body bone mineral content (TBBMC), lean body mass (LBM) and fat mass (FM) was calculated from the scan data using the new total body composition scan software (version 2.5.2). The in vivo day-to-day imprecision (coefficient of variation, CV%) are 1.5%, 1.4% and 1.2% for the TBBMC, LBM and FM measurements, respectively (according to repeated measurements of 18 subjects, unpublished data). The scanner was calibrated daily, and its performance was monitored with our quality assurance protocol (Sievanen et al., 1994).

In addition to whole body data, the analysis provides data on regional BMC, LBM, and FM from head, trunk, abdomen, arms (both), and legs (both). The segmental FFM was calculated by a sum of regional BMC and LBM.

5.4. Segmental multi-frequency bioimpedance analysis

The body composition was assessed by segmental multi-frequency bioimpedance analysis (SMFBIA) (InBody 3.0 Biospace Co. Ltd. Soul, South-Korea). The InBody 3.0 uses 8-point tactile electrode, multi-frequency and segmental measurement method. The measurement is performed in upright position in contrast with classical methods (Picture1). For feet InBody 3.0 is equipped with total four stainless steel electrodes, two under each foot, one for heel and one for rear sole. The hand electrodes are constructed from metal foil coated electrodes, for palms and thumbs, mounted in two plastic handles, totally four electrodes (Picture 2). These electrodes are connected to the current and voltage supply of the device. Impedance is then measured trough on-off switches regulated by microprocessor of the InBody 3.0 device. By regulation of these switches in appropriate order the impedance from different body segments can be accordingly detected. The body segments measured were left and right hand, trunk, and left and right leg. The multi-frequency measurement is conducted by using multiple frequencies at 5 kHz, 50 kHz, 250 kHz, and 500 kHz. The microprocessor regulates also switching for different frequencies (Cha et al., 1995).

Table 5. Examples of body composition methods.

Category	Equation	Reference method	Reference
Type I property-based methods	Fat = 0.65 x BW - 0.21 x Ht + 14.1	Anthropometry	
	FFM = 0.85 x Ht^2/Z + 3.04	Bioimpedance analysis	
	SM = 18.9 x Cre + 4.1	24-h urinary creatinine excretion	(Lukaski et al., 1985)
			(Wang et al., 1996)
Type II property-based methods	Fat = 4.95 x BV - 4.50 x BW	Hydrodensitometry	(Behnke et al., 1942)
	FFM = 5.50 x BW - 4.95 x BV	Hydrodensitometry	
Type I component-based methods	Protein = 0.335 x TBW - 2.53	Tracer dilution	(Beddoe and Hill, 1985)
Type II component-based methods	Protein = 6.25 x TBN	Prompt- IVNA gg	(Cunningham, 1994)
	FFM = 1.37 x TBW	Tracer dilution	(Pace and Rathbun,
	BCM = 213 x TBK	Whole-body ^{40}K counting	(Modlesky et al., 1996)
	Fat = 1.30 x TBC - 4.45 x TBN - 0.06 x TBCa	Prompt-gg IVNA and inelastic neutron scattering	(Kehayias et al., 1991)

Abbreviation: BW, body weight; Ht, height; FFM, fat-free body mass; Z, electrical impedance; SM, skeletal muscle; Cre, 24-h urinary creatinine excretion; BV, body volume; TBW, total body water; TB, total body; BCM, body cell mass; IVNA, in vivo neutron activation (Modified from Pace and Rathbun, 1945; Heymsfield et al., 1997).

Table 6. Characteristics of subject group (*n = 40*).

n = 40	Mean	SD	Min.	Max.	Range
Age (years)	45.3	5.0	36.0	53.0	17.0
Height (cm)	176.9	4.5	167.0	185.0	18.0
Weight (kg)	96.7	9.7	81.4	127.1	45.6
BMI	30.9	3.1	26.0	40.7	14.8
Waist (cm)	104.1	8.4	88.0	126.0	38.0
Hip (cm)	105.6	5.1	93.0	120.0	27.0
WHR	.99	.056	.88	1.15	.27
UWW body density	1.026	.0101	1.000	1.040	.040

The measurement takes about two minutes time, where after the device prints the result sheet (Appendix 1) through a standard personal computer printer connected to the InBody 3.0 measurement device.

InBody 3.0 device report gives total body FFM, FM, and F% values calculated from impedance values, equation reported earlier (Cha et al., 1995). The segmental FFM was calculated from segmental fluid distribution with assumption of constant body water content of FFM equals 0.732 L per kg (Wang et al., 1999).

SMFBIA measurements were carried out according to general recommendations. The measurements were performed after 12-hour fasting and within 30 minutes of voiding the urinary bladder. No physical exercise was allowed before 4 hours of the measurement (NIH, 1996a; 1996b).

5.5. Statistical analysis

The data are expressed as means ±SD, min, max, and range. The Pearson correlation coefficient between assessment methods was calculated for F%, FM and FFM. Statistical significance was assessed using Paired-Samples t-test for correlated samples P values of less than 0.05 were considered statistically significant. Bland-Altman analysis was used to compare methods against each other (Altman and Bland, 1983; Bland and Altman, 1986). Bland-Altman analysis is a statistical method where one compares a mean difference against average values from two different methods. The variation between methods are then presented as a ±2SD, which represents 95% limit of agreement. The data were analyzed using the statistical package SPSS for Windows, PC software, version 11.5.1 (SPSS Inc., Chicago, IL, USA).

6. RESULTS

6.1. Total body composition

The mean whole body FM (±SD%) from UWW was 31.5 kg (±7.3). By DXA, it was 29.9 kg (±8.1) and by SMFBIA, it was 25.5 kg (±7.6), respectively. The mean whole body FFM (±SD%) was similarly from UWW 65.2 kg (±5.1). By DXA it was 66.8 kg (±6.0) and by SMFBIA it was 71.9 kg (±5.5), respectively. Again, the mean whole body F% (±SD%) from UWW was 32.3 % (±4.8). By DXA it was 30.6 % (±5.9) and by SMFBIA it was 25.9 % (±5.6), respectively. The mean values with SD; minimal, maximal and range values are presented in Table 7.

Table 7. FM, FFM and F% mean values from UWW, DXA and, SMFBIA with SD, min, max and, range values, respectively.

n = 40	Mean	SD	Min	Max	Range
UWW FM (kg)	31.5	7.3	23.1	53.6	30.6
DXA FM (kg)	29.9	8.1	17.0	56.9	39.9
SMFBIA FM (kg)	25.5	7.6	12.0	48.8	36.8
UWW FFM (kg)	65.2	5.1	52.4	78.2	25.9
DXA FFM (kg)	66.8	6.0	57.2	79.8	22.6
SMFBIA FFM (kg)	71.9	5.5	62.0	80.7	18.7
UWW F%	32.3	4.8	25.4	46.6	21.3
DXA F%	30.6	5.9	18.6	49.4	30.8
SMFBIA F%	25.9	5.6	13.0	42.1	29.1

Picture 1. InBody 3.0 SMFBIA measurement device and upright measurement position.

Picture 2. Hand and feet electrodes of InBody 3.0 SMFBIA device.

The Pearson correlation coefficients between UWW, DXA and SMFBIA from FM, FFM and F% are presented in Table 8. All the correlations are statistically significant ($p < 0.01$). Furthermore, the correlation regressions are plotted from F% in Figure 9, FM in Figure 10 and FFM in Figure 11.

Table 8. Pearson correlation coefficient matrix of measured variables (FM, FFM and F%) from UWW, DXA and SMFBIA.

n = 40	**UWW FM**	**DXA FM**	**SMFBIA FM**
UWW FM	1.0	-	-
DXA FM	.91	1.0	-
SMFBIA FM	.91	.94	1.0
n = 40	**UWW FFM**	**DXA FFM**	**SMFBIA FFM**
UWW FFM	1.0	-	-
DXA FFM	.82	1.0	-
SMFBIA FFM	.83	.88	1.0
n = 40	**UWW F%**	**DXA F%**	**SMFBIA F%**
UWW F%	1.0	-	-
DXA F%	.80	1.0	-
SMFBIA F%	.81	.88	1.0

Bland-Altman analysis was calculated as a mean difference against average values with ±2SD for F%, FM, and FFM, from UWW, DXA and, SMFBIA, respectively. The values are presented in Table 9 and plotted in Figures 9, 10 and, 11.

6.2. Segmental body composition

The mean segmental FFM (arms, trunk and legs) values from DXA and SMFBIA with SD, minimal, maximal and range values are presented in Table 10.

Pearson correlation coefficient between DXA and SMFBIA of FFM in different body segments are presented in Table 11. All the correlations are statistically significant ($p < 0.01$). Furthermore, the correlation regressions from different body segments are plotted in Figure 9.

Bland-Altman analysis was calculated as a mean difference against average values with ±2SD for FFM between DXA and SMFBIA from each segment, arms, legs and, trunk. The values are presented in Table 12 and plotted in Figure 12.

Table 9. Bland-Altman analysis, mean difference, average values and, ±2SD from FM, FFM and, F% between different methods, respectively.

n = 40	**Mean**	**±2SD**
UWW-SMFBIA FM (kg)	6.0	6.2
DXA-SMFBIA FM (kg)	4.4	5.6
UWW-DXA FM (kg)	1.6	6.8
(UWW+SMFBIA)/2 mean FM (kg)	28.5	14.6
(DXA+SMFBIA)/2 mean FM (kg)	27.7	15.5
(UWW+DXA)/2 mean FM (kg)	30.7	15.0
n = 40	**Mean**	**±2SD**
UWW-SMFBIA FFM (kg)	– 6.7	6.2
DXA-SMFBIA FFM (kg)	– 5.0	5.7
UWW-DXA FFM (kg)	– 1.6	6.8
(UWW+SMFBIA)/2 mean FFM (kg)	68.6	10.2
(DXA+SMFBIA)/2 mean FFM (kg)	69.4	11.1
(UWW+DXA)/2 mean FFM (kg)	66.0	10.6
n = 40	**Mean**	**±2SD**
UWW-SMFBIA F%	6.4	6.5
UWW-DXA F%	1.7	7.1
DXA-SMFBIA F%	4.7	5.7
(UWW+SMFBIA)/2 mean F%	29.1	9.9
(UWW+DXA)/2 mean F%	31.4	10.1
(DXA+SMFBIA)/2 mean F%	28.2	11.1

Table 10. Segmental mean FFM values from DXA and SMFBIA with SD, min, max and range values

n = 40	**Mean**	**SD**	**Min.**	**Max.**	**Range**
FFM arms DXA (kg)	7.7	1.0	5.5	9.9	4.4
FFM trunk DXA (kg)	41.7	4.6	32.9	54.2	21.3
FFM legs DXA (kg)	21.9	2.2	18.3	26.9	8.7
FFM arms SMFBIA (kg)	8.5	.9	7.0	10.8	3.9
FFM trunk SMFBIA (kg)	31.7	2.5	27.1	37.7	10.6
FFM legs SMFBIA (kg)	20.3	1.6	17.3	23.0	5,7

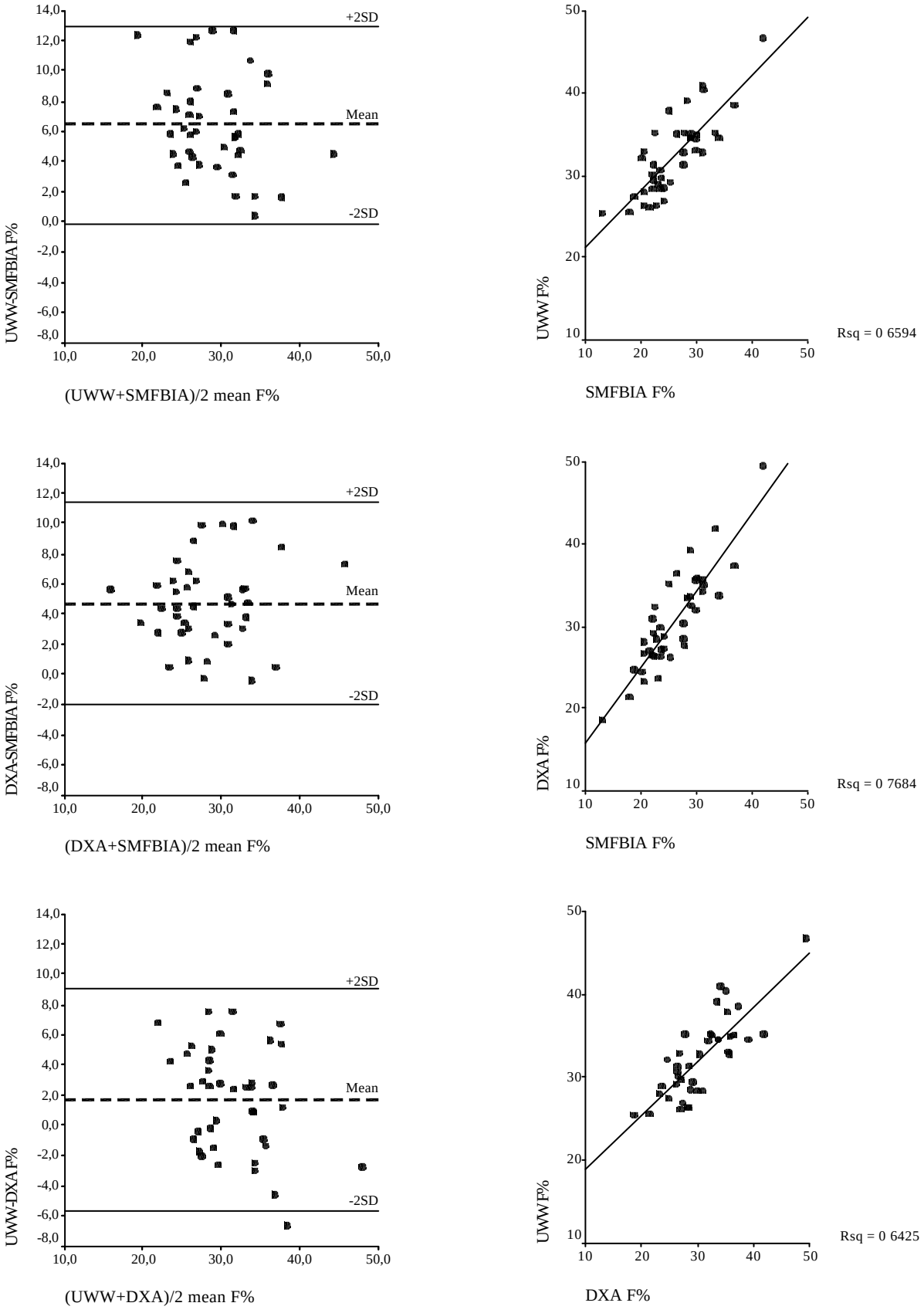


Figure 9. Pearson correlation coefficient and Bland-Altman analysis plotted from F% between all methods.

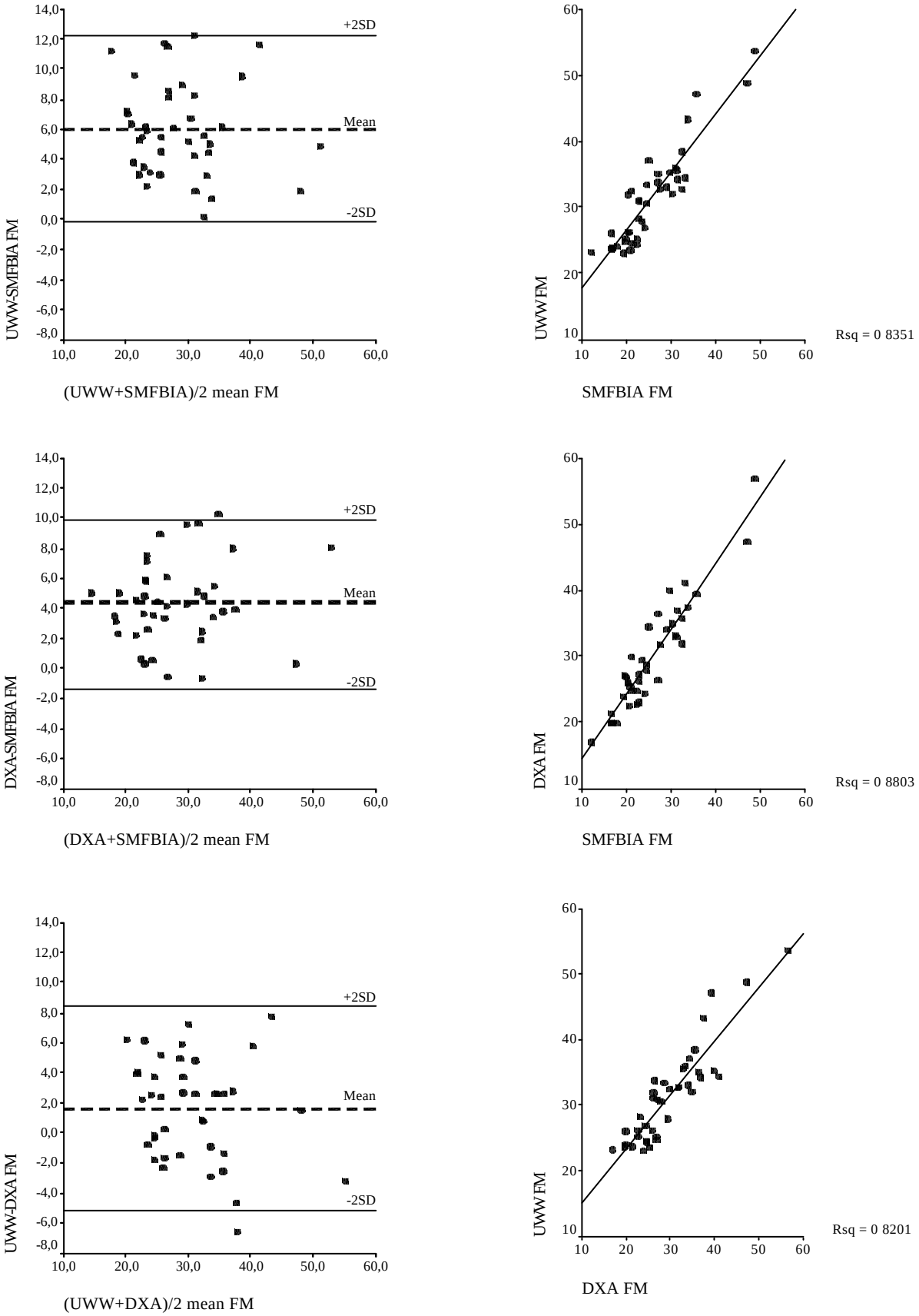


Figure 10. Pearson correlation coefficient and Bland-Altman analysis plotted from FM between all methods.

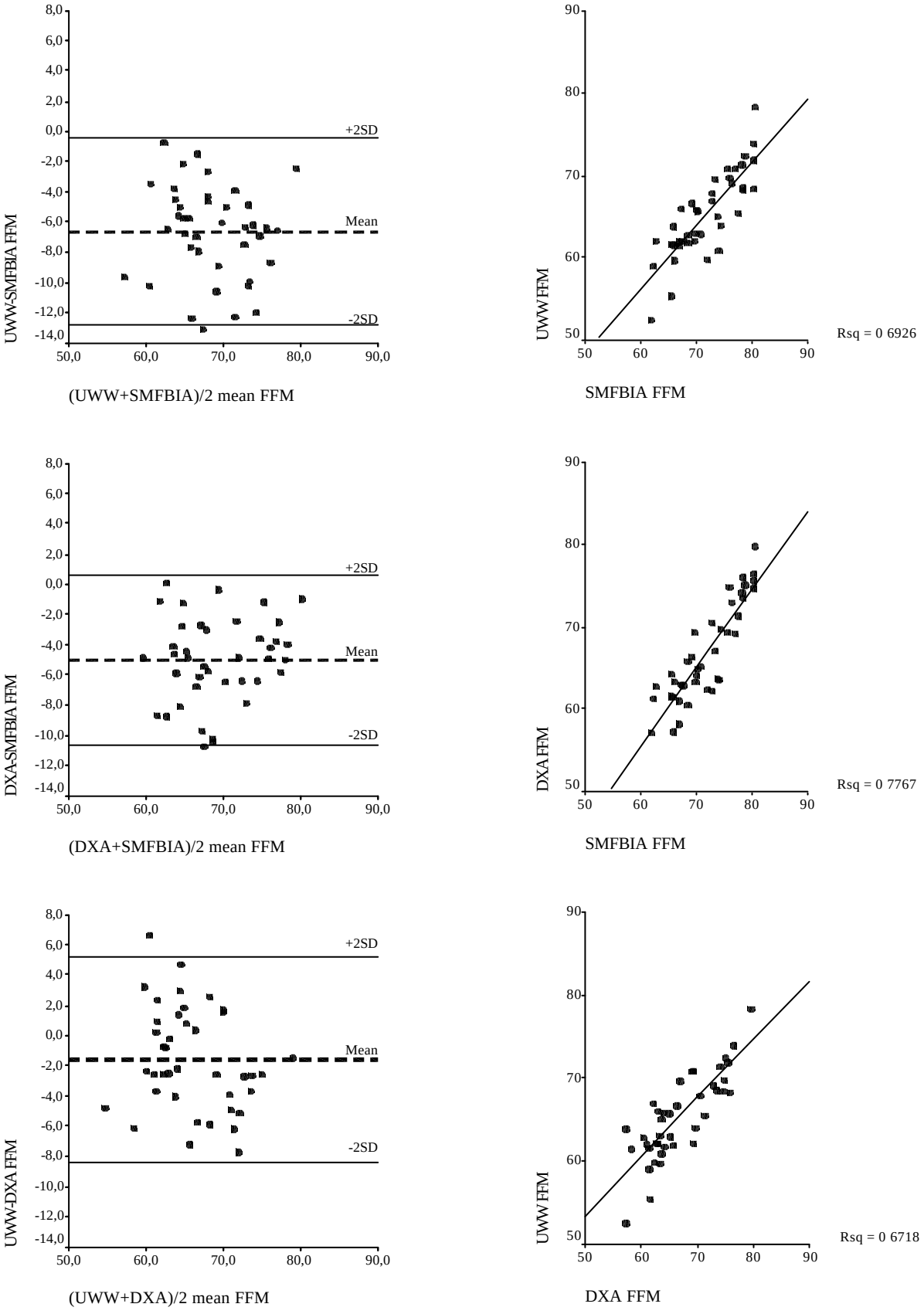


Figure 11. Pearson correlation coefficient and Bland-Altman analysis plotted from FMM between all methods.

7. DISCUSSION

This thesis describes body composition assessment principles and methods. One important decision when selecting the method is to understand the model behind it. The whole body model includes total body weight, height and other anthropometric measures. Probably the most used body composition assessment model in clinical and scientific use is the molecular model. It is valuable in most cases when assessing fat and fat free ratios against total body weight. In research and clinical diagnostic purposes, one can benefit about a data from atomic or cellular models. In addition, in clinical use the functional model can be beneficial. If high accuracy of body composition estimates in individuals is essential, multi-component models are recommended to be used (Fogelholm and van Marken Lichtenbelt, 1997).

Table 11. Pearson correlation coefficient between DXA and SMFBIA from different body parts (arms, trunk and legs).

n = 40	FFM arms SMFBIA	FFM trunk SMFBIA	FFM legs SMFBIA
FFM arms DXA	.75	-	-
FFM trunk DXA	-	.77	-
FFM legs DXA	-	-	.72

In our study, we evaluated SMFBIA in 2-C model and estimated FM, F% and FFM compared to UWW and DXA. The study sample represented a sample of 40 overweighed male subjects. The correlations between methods were high in all cases. The highest correlations were found between SMFBIA and DXA. Similar results have been demonstrated earlier, for example by Bracco et al. reported a comparison between BIA and DXA with a same trend in the results (Bracco et al., 1996). The known fact of overestimation FFM by BIA existed also in our results. That is the primary reason for, despite the high correlation between the methods, a relatively poor result from Bland-Altman analysis. This is especially seen in comparison between SMFBIA and DXA.

The second objective in our study was to compare segmental distribution of FFM between SMFBIA and DXA. Similar studies have been performed for adults (Bracco et al., 1996) and children (Fuller et al., 2002), before. In segmental body composition assessment by SMFBIA, we faced similar fears as described earlier about problems with segmental assessment. By accepting these facts, we made our analysis with device manufacturer based equations and software. Our fears became true and we found a nice correlation and an acceptable range of difference in Bland-Altman analysis for leg and arm sections of the body. The correlation for trunk area was also high, but a big difference was seen in Bland-Altman analysis. Moreover, the Bland-Altman plot shows a remarkable bias in the ends of the measurement range. In the other words, subjects with low or high FFM are showing bigger error in analysis. This is probably a reason for low impedance at the trunk area from SMFBIA that cannot recognise differences accurately at this body segment.

Table 12. Bland-Altman analysis, FFM mean difference, average values and, ±2SD from arms, trunk and, legs between DXA and SMFBIA, respectively.

n = 40	Mean	±2SD
DXA - SMFBIA FFM arms (kg)	–.8	1.3
DXA - SMFBIA FFM trunk (kg)	10.0	12.4
DXA - SMFBIA FFM legs (kg)	1.6	3.0
(DXA+SMFBIA)/2 mean FFM arms (kg)	8.1	1.7
(DXA+SMFBIA)/2 mean FFM trunk (kg)	36.7	6.7
(DXA+SMFBIA)/2 mean FFM legs (kg)	21.1	3.6

However, the trend is good enough to take advance of the benefit what a segmental analysis can provide, especially in upper and lower extremities, e.g. for assessment of possible side differences in clinical conditions. In addition, the feasibility of the measurement procedure may enhance the use of SMFBIA in epidemiological studies.

BIA is a widely used method for estimating body composition. Wide range of measuring apparatus exists for field and clinical use. BIA and its accuracy are dependent on apparatus and valid choice of prediction equation used (Heitmann, 1994; Ellis, 2001). BIA have been used successfully in large epidemiological studies for example in United States (Chumlea et al., 2002), Switzerland (Pichard et al., 2000; Kyle et al., 2001) and Denmark (Heitmann, 1991). Segmental and multi-frequency

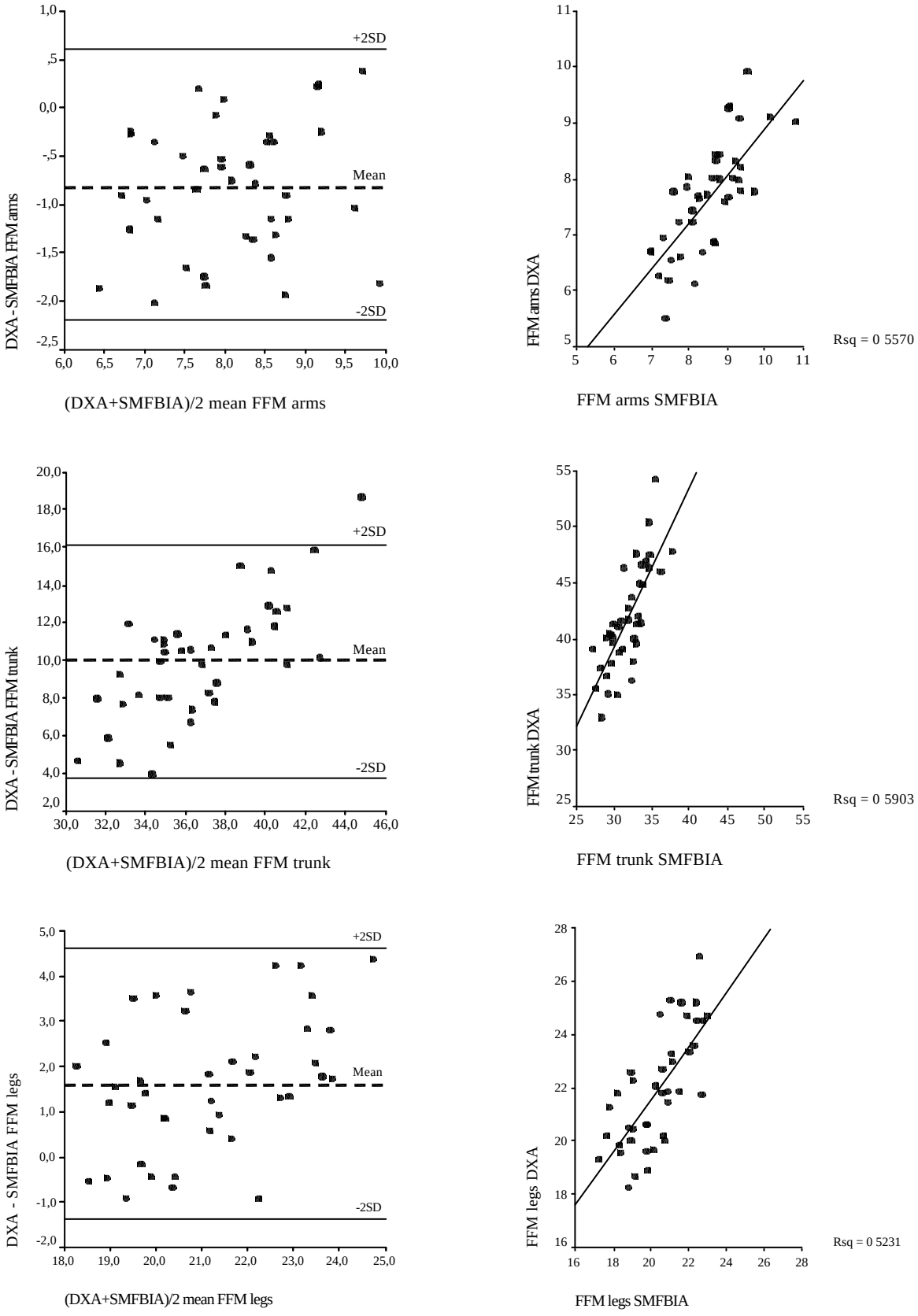


Figure 12. Pearson correlation coefficient and Bland-Altman analysis plotted from segmental FFM between DXA and SMFBIA.

features for BIA have been developed for increasing accuracy and more individual assessment of the body composition. Multi-frequency capability of the BIA measurement has definitely brought some advance in accuracy of the assessment (Ellis et al., 1999a). Furthermore, differentiation of ICF and ECF has been possible along with multi-frequency measurement (Gudivaka et al., 1999). Segmental measurement feature on the other hand seems to be interesting but challenging task according to the accuracy. Of course, individual differences in body shape and tissue distribution give a good reason for developing segmental procedure. However, the method is hard to validate against other methods because of different body segment differentiation between measuring devices. Besides, exact body segment differentiation by SMFBIA is probably the most difficult. In BIA, electrical current pathway is against lowest resistance available in human body. Furthermore, by knowing, that SMFBIA gives highest impedance values from extremities and lowest from the trunk area while the volumes in these body parts are opposite, which makes the valid assessment difficult.

Whatever body composition model or method is used the knowledge about them is a must. Furthermore, understanding the confounding factors, sources of error and other possible biases inherent in these methods is crucial for valid body composition estimate. Hydration state of the subject seems to play an important role in most of the methods. MRI is based on the position of the hydrogen atoms. DXA is also sensitive of the hydration of FFM and BIA is primarily measuring total body water content or ratio of ICF and ECF, where hydration state of the subject can mislead the analysis remarkably (Montagnani et al., 1998; Pietrobelli et al., 1998b).

Very lean or obese subjects can cause great error in their body composition estimate. Most of the equations used with these different methods are based on population based studies with subjects close to the average body composition values. Therefore, the error in the body composition assessment seems to grow when lean or obese subjects are in question. Here, also, the different hydration status within these marginal groups may explain some of the bigger error (Fogelholm et al., 1996; Fogelholm and van Marken Lichtenbelt, 1997).

At ageing, people tend to gain fat and lose muscle without an obvious change in their weight. This is also in part originated from the reason of decreasing hydration in the muscle tissue in aging (Baumgartner, 2000; Wang et al., 2000). Furthermore, gender differences occur when estimating body composition. The differences in hormonal secretion have impacts in body composition as well (Heitmann, 1991). Besides, changes in hormonal state in females during the menstrual cycle should be taken in the consideration when analysing body constitution (Gleichauf and Roe, 1989). Hence, one has to be aware about these varying situations when performing valid body composition assessment.

One of the major confounding factor in the field of body composition estimation, despite what method is in question, is the wide variety of prediction equations. It is understandable because of individual differences between genders, ages, races, etc. Nevertheless, it makes comparison between different studies and interventions, if not impossible, at least difficult and unreliable. That could be the general task for body composition research in the future. Moreover, body composition assessment in childhood is crucial task in the follow up for breaking the trend of growing obesity (James et al., 2001). Therefore, generally accepted prediction equations at least for children are needed for all the major body composition assessment methods.

Body composition assessment is an important method needed in the field of fighting global epidemic of obesity. Body composition reflects the balance of physical activity (energy consumption) and nutritional habits (energy supply). The scale can be very misleading. Body weight alone cannot tell the difference between the amount of fat and muscle (Heitmann and Garby, 2002). And, even though we need a certain amount of fat in our bodies to insure good health, excess body fat has been found to increase the risk of diseases such as type II diabetes (Smith and Ravussin, 2002), cardiovascular disease (Rashid et al., 2003) and cancer (Calle et al., 2003). Only by accurately analysing body composition, you will find the precise amount of fat and lean tissue that makes up your weight, enabling right decisions regarding nutrition and exercise programs. In addition, when studying the overweight or obesity from self-reported data it can mislead the results dramatically. The results from self-reported measures may lead to around 30% misclassification of body composition (Wang et al., 2002). Therefore accurate and objective body composition assessment is essential for the weight management.

At present population based reference values are not available for any body composition assessment method, only for some anthropometric measures. As a feasible field method, SMFBIA is a potential also for large population based studies. In

this situation, there is a need for body composition values and trends for different populations. These should include percentiles of FM, FFM and F% in different age groups and genders. Also, further investigation is needed for finding out the predictive value of segmental body composition and its distribution when assessing the risk of e.g. chronic obesity related disorders; metabolic syndrome, type II diabetes, high blood pressure, cardio vascular diseases and, arthritis.

8. CONCLUSION

The purpose of this study was to evaluate segmental multi-frequency bioimpedance method (SMFBIA) in body composition assessment.

The present study confirms that SMFBIA is usefull method to evaluate whole body fat mass (FM), fat percentage (F%) and fat free mass (FFM).

Furthermore, this study shows some new evidence that SMFBIA is suitable method for assessing segmental distribution of FFM from upper and lower extremities compared to whole body DXA. Assessment from trunk area remained uncertain in our study.

Further research is needed for creating segmental population based reference values from SMFBIA. These should include percentiles of FM, FFM and F% in different age groups and genders.

Also further research is required for finding out the predictive value of segmental body composition for diseases e.g. chronic obesity related disorders. In addition, to evaluate strength of the value of segmental body composition assessment alone and in association with general anthropometric measures when predicting the risk of these pathological conditions.

9. REFERENCES

Abate, N., Burns, D., Peshock, R. M., Garg, A. and Grundy, S.M. (1994) Estimation of adipose tissue mass by magnetic resonance imaging: validation against dissection in human cadavers. *Journal of Lipid Research* **35**, 1490-1496.

Altman, D.G. and Bland, J.M. (1983) Measurement in Medicine: The Analysis of Method Comparison Studies. *The Statistician* **32**, 307-317.

Aromaa, A. and Koskinen, S. (2002) Health and functional capacity in Finland. Baseline results of the Health 2000 health examination survey. *Publications of the National Public Health Institute*, National Public Health Institute, Helsinki. p. 148.

Baumgartner, R.N. ℓ000) Body composition in healthy aging. *Annals of New York Academy of Science* **904**, 437-448.

Baumgartner, R.N., Heymsfield, S.B., Roche, A.F. and Bernardino, M. (1988) Abdominal composition quantified by computed tomography. *American Journal of Clinical Nutrition* **48**, 936-945.

Baumgartner, R.N., Rhyne, R.L., Troup, C., Wayne, S. and Garry, P.J. (1992) Appendicular skeletal muscle areas assessed by magnetic resonance imaging in older persons. *Journal of Gerontology* **47**, M67-72.

Beddoe, A.H. and Hill, G.L. (1985) Clinical measurement of body composition using in vivo neutron activation analysis. *Journal of Parenteral and Enteral Nutrition* **9**, 504-520.

Bedogni, G., Malavolti, M., Severi, S., Poli, M., Mussi, C., Fantuzzi, A.L. and Battistini, N. (2002) Accuracy of an eight-point tactile-electrode impedance method in the assessment of total body water. *European Journal of Clinical Nutrition* **56**, 1143-1148.

Behnke, A., Feen, B. and Wc, W. (1942) The specific gravity of healthy men. *Journal of The American Medical Assossiation* **118**, 495-498.

Bland, J.M. and Altman, D.G. (1986) Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* **1**, 307-310.

Borg, P., Kukkonen-Harjula, K., Fogelholm, M. and Pasanen, M. (2002) Effects of walking or resistance training on weight loss maintenance in obese, middle-aged men: a randomized trial. *International Journal of Obesity and Related Metabolic Disorders* **26**, 676-683.

Bracco, D., Thiebaud, D., Chiolero, R. L., Landry, M., Burckhardt, P. and Schutz, Y. (1996) Segmental body composition assessed by bioelectrical impedance analysis and DEXA in humans. *Journal of Applied Physiology* **81**, 2580-2587.

Brozek, J. (1966) Body composition: models and estimation equations. *American Journal of Physical Anthropology* **24**, 239-246.

Calle, E.E., Rodriguez, C., Walker-Thurmond, K. and Thun, M.J. (2003) Overweight, obesity, and mortality from cancer in a prospectively studied cohort of U.S. adults. *New England Journal of Medecine* **348**, 1625-1638.

Caton, J.R., Mole, P.A., Adams, W.C. and Heustis, D.S. (1988) Body composition analysis by bioelectrical impedance: effect of skin temperature. *Medicine and Science in Sport and Exercise* **20**, 489-491.

Cha, K., Chertow, G.M., Gonzalez, J., Lazarus, J.M. and Wilmore, D.W. (1995) Multifrequency bioelectrical impedance estimates the distribution of body water. *Journal of Applied Physiology* **79**, 1316-1319.

Chumlea, W.C., Baumgartner, R.N. and Mitchell, C.O. (1990) The use of segmental bioelectric

impedance in estimating body composition. *Basic Life Science* **55**, 375-385.

Chumlea, W.C., Baumgartner, R.N. and Roche, A.F. (1988) Specific resistivity used to estimate fat-free mass from segmental body measures of bioelectric impedance. *American Journal of Clinical Nutrition* **48**, 7-15.

Chumlea, W.C., Guo, S.S., Kuczmarski, R.J., Flegal, K.M., Johnson, C.L., Heymsfield, S.B., Lukaski, H.C., Friedl, K. and Hubbard, V.S. (2002) Body composition estimates from NHANES III bioelectrical impedance data. *International Journal of Obesity and Related Metabolic Disorders* **26**, 1596-1609.

Conway, J.M., Norris, K.H. and Bodwell, C. E. (1984) A new approach for the estimation of body composition: infrared interactance. *American Journal of Clinical Nutrition* **40**, 1123-1130.

Cunningham, J.J. (1994) N x 6.25: recognizing a bivariate expression for protein balance in hospitalized patients. *Nutrition* **10**, 124-127.

Dempster, P. and Aitkens, S. (1995) A new air displacement method for the determination of human body composition. *Medicine and Science in Sport and Exercise* **27**, 1692-1697.

Elia, M., Parkinson, S.A. and Diaz, E. (1990) Evaluation of near infra-red interactance as a method for predicting body composition. *European Journal of Clinical Nutrition* **44**, 113-121.

Ellis, K. J. (2000) Human Body Composition: In Vivo Methods. *Physiol. Rev.* **80**, 649-680.

Ellis, K. J. (2001) Selected body composition methods can be used in field studies. *Journal of Nutrition* **131**, 1589S-1595S.

Ellis, K.J., Bell, S.J., Chertow, G.M., Chumlea, W.C., Knox, T.A., Kotler, D.P., Lukaski, H.C. and Schoeller, D.A. (1999a) Bioelectrical impedance methods in clinical research: a follow-up to the NIH Technology Assessment Conference. *Nutrition* **15**, 874-880.

Ellis, K.J., Shypailo, R.J. and Wong, W.W. (1999b) Measurement of body water by multifrequency bioelectrical impedance spectroscopy in a multiethnic pediatric population. *American Journal of Clinical Nutrition* **70**, 847-853.

Fogelholm, G.M., Kukkonen-Harjula, T.K., Sievanen, H.T., Oja, P. and Vuori, I.M. (1996) Body composition assessment in lean and normal-weight young women. *British Journal of Nutrition* **75**, 793-802.

Fogelholm, G.M., Sievanen, H.T., van Marken Lichtenbelt, W.D. and Westerterp, K. R. (1997) Assessment of fat-mass loss during weight reduction in obese women. *Metabolism* **46**, 968-975.

Fogelholm, M., Sievanen, H., Kukkonen-Harjula, K., Oja, P. and Vuori, I. (1993) Effects of meal and its electrolytes on bioelectrical impedance. *Basic Life Science* **60**, 331-332.

Fogelholm, M. and van Marken Lichtenbelt, W. (1997) Comparison of body composition methods: a literature analysis. *European Journal of Clinical Nutrition* **51**, 495-503.

Fuller, N.J., Fewtrell, M.S., Dewit, O., Elia, M. and Wells, J.C. (2002) Segmental bioelectrical impedance analysis in children aged 8-12 y: 2. The assessment of regional body composition and muscle mass. *International Journal of Obesity and Related Metabolic Disorders* **26**, 692-700.

Gleichauf, C.N. and Roe, D.A. (1989) The menstrual cycle's effect on the reliability of bioimpedance measurements for assessing body composition. *American Journal of Clinical Nutrition* **50**, 903-907.

Goodpaster, B.H., Thaete, F.L. and Kelley, D.E. (2000) Composition of skeletal muscle evaluated with computed tomography. *Annals of New York Academy of Science* **904**, 18-24.

Gudivaka, R., Schoeller, D. and Kushner, R.F. (1996) Effect of skin temperature on multifrequency bioelectrical impedance analysis. *Journal of Applied Physiology* **81**, 838-845.

Gudivaka, R., Schoeller, D.A., Kushner, R.F., and Bolt, M.J. (1999) Single- and multifrequency models for bioelectrical impedance analysis of body water compartments. *Journal of Applied Physiology* **87**, 1087-1096.

Heitmann, B.L. (1991) Body fat in the adult Danish population aged 35-65 years: an epidemiological study. *International Journal of Obesity and Related Metabolic Disorders* **15**, 535-545.

Heitmann, B.L. (1994) Impedance: a valid method in assessment of body composition? *European Journal of Clinical Nutrition* **48**, 228-240.

Heitmann, B.L. and Garby, L. (2002) Composition (lean and fat tissue) of weight changes in adult Danes. *American Journal of Clinical Nutrition* **75**, 840-847.

Heymsfield, S.B., Fulenwider, T., Nordlinger, B., Barlow, R., Sones, P. and Kutner, M. (1979a) Accurate measurement of liver, kidney, and spleen volume and mass by computerized axial tomography. *Annals of Internal Medicine* **90**, 185-187.

Heymsfield, S.B., Olafson, R.P., Kutner, M.H. and Nixon, D.W. (1979b) A radiographic method of quantifying protein-calorie undernutrition. *American Journal of Clinical Nutrition* **32**, 693-702.

Heymsfield, S.B., Wang, J., Kehayias, J., Heshka, S., Lichtman, S. and Pierson, R.N., Jr. (1989) Chemical determination of human body density in vivo: relevance to hydrodensitometry. *American Journal of Clinical Nutrition* **50**, 1282-1289.

Heymsfield, S.B., Wang, Z., Baumgartner, R.N. and Ross, R. (1997) Human body composition: advances in models and methods. *Annual Review of Nutrition* **17**, 527-558.

James, P.T., Leach, R., Kalamara, E. and Shayeghi, M. (2001) The worldwide obesity epidemic. *Obesity Research* **9 Suppl 4**, 228S-233S.

Janssen, I., Heymsfield, S.B., Allison, D.B., Kotler, D.P. and Ross, R. (2002) Body mass index and waist circumference independently contribute to the prediction of nonabdominal, abdominal subcutaneous, and visceral fat. *American Journal of Clinical Nutrition* **75**, 683-688.

Kehayias, J.J., Heymsfield, S.B., LoMonte, A.F., Wang, J. and Pierson, R.N., Jr. (1991) In vivo determination of body fat by measuring total body carbon. *American Journal of Clinical Nutrition* **53**, 1339-1344.

Kyle, U.G., Genton, L., Slosman, D.O. and Pichard, C. (2001) Fat-free and fat mass percentiles in 5225 healthy subjects aged 15 to 98 years. *Nutrition* **17**, 534-541.

Lahti-Koski, M. (2001) Body Mass Index and Obesity Among Adults in Finland. *Department of Epidemiology and Health Promotion, National Public Health Institute and Department of Public Health*, Academic Dissertation, University of Helsinki, Helsinki. , p. 102.

Levenhagen, D.K., Borel, M.J., Welch, D.C., Piasecki, J.H., Piasecki, D.P., Chen, K.Y. and Flakoll, P.J. (1999) A comparison of air displacement plethysmography with three other techniques to determine body fat in healthy adults. *Journal of Parenteral and Enteral Nutrition* **23**, 293-299.

Liang, M.T. and Norris, S. (1993) Effects of skin blood flow and temperature on bioelectric impedance after exercise. *Medicine and Science in Sport and Exercise* **25**, 1231-1239.

Liang, M.T., Su, H.F. and Lee, N.Y. (2000) Skin temperature and skin blood flow affect bioelectric impedance study of female fat-free mass. *Medicine and Science in Sport and Exercise* **32**, 221-227.

Lukaski, H.C., Johnson, P.E., Bolonchuk, W.W. and Lykken, G.I. (1985) Assessment of fat-free mass using bioelectrical impedance measurements of the human body. *American Journal of Clinical Nutrition* **41**, 810-817.

Mazess, R.B., Barden, H.S., Bisek, J.P. and Hanson, J. (1990) Dual-energy x-ray absorptiometry for total-body and regional bone-mineral and soft-tissue composition. *American Journal of Clinical Nutrition* **51**, 1106-1112.

McCrory, M.A., Gomez, T.D., Bernauer, E.M. and Mole, P.A. (1995) Evaluation of a new air displacement plethysmograph for measuring human body composition. *Medicine and Science in Sport and Exercise* **27**, 1686-1691.

McCrory, M.A., Mole, P.A., Gomez, T.D., Dewey, K.G. and Bernauer, E.M. (1998) Body composition by air-displacement plethysmography by using predicted and measured thoracic gas volumes. *Journal of Applied Physiology* **84**, 1475-1479.

McLean, K.P. and Skinner, J.S. (1992) Validity of Futrex-5000 for body composition determination. *Medicine and Science in Sport and Exercise* **24**, 253-258.

Mitsiopoulos, N., Baumgartner, R.N., Heymsfield, S.B., Lyons, W., Gallagher, D. and Ross, R. (1998) Cadaver validation of skeletal muscle measurement by magnetic resonance imaging and computerized tomography. *Journal of Applied Physiology* **85**, 115-122.

Modlesky, C.M., Lewis, R.D., Yetman, K.A., Rose, B., Rosskopf, L.B., Snow, T.K. and Sparling, P.B. (1996) Comparison of body composition and bone mineral measurements from two DXA instruments in young men. *American Journal of Clinical Nutrition* **64**, 669-676.

Molarius, A. and Seidell, J.C. (1998) Selection of anthropometric indicators for classification of abdominal fatness--a critical review. *International Journal of Obesity and Related Metabolic Disorders* **22**, 719-727.

Molarius, A., Seidell, J.C., Sans, S., Tuomilehto, J. and Kuulasmaa, K. (1999a) Waist and hip circumferences, and waist-hip ratio in 19 populations of the WHO MONICA Project. *International Journal of Obesity and Related Metabolic Disorders* **23**, 116-125.

Molarius, A., Seidell, J.C., Sans, S., Tuomilehto, J. and Kuulasmaa, K. (1999b) Varying sensitivity of waist action levels to identify subjects with overweight or obesity in 19 populations of the WHO MONICA Project. *Journal of Clinical Epidemiology* **52**, 1213-1224.

Montagnani, M., Montomoli, M., Mulinari, M., Guzzo, G., Scopetani, N. and Gennari, C. (1998) Relevance of hydration state of the fat free mass in estimating fat mass by body impedance analysis. *Appllied Radiation and Isotopes* **49**, 499-500.

Morgan, W. D. (2000) Of mermaids and mountains. Three decades of prompt activation in vivo. *Annals of New York Academy of Science* **904**, 128-133.

NIH (1996a) Bioelectrical impedance analysis in body composition measurement: National Institutes of Health Technology Assessment Conference Statement. *American Journal of Clinical Nutrition* **64**, 524S-532S.

NIH (1996b) NIH Consensus statement. Bioelectrical impedance analysis in body composition measurement. National Institutes of Health Technology Assessment Conference Statement. December 12-14, 1994. *Nutrition* **12**, 749-762.

Nordhamn, K., Sodergren, E., Olsson, E., Karlstrom, B., Vessby, B. and Berglund, L. (2000) Reliability of anthropometric measurements in overweight and lean subjects: consequences for correlations between anthropometric and other variables. *International Journal of Obesity and Related Metabolic Disorders* **24**, 652-657.

Ohrvall, M., Berglund, L. and Vessby, B. (2000) Sagittal abdominal diameter compared with other anthropometric measurements in relation to cardiovascular risk. *International Journal of*

Obesity and Related Metabolic Disorders **24**, 497-501.

Organ, L.W., Bradham, G.B., Gore, D.T. and Lozier, S.L. (1994) Segmental bioelectrical impedance analysis: theory and application of a new technique. *Journal of Applied Physiology* **77**, 98-112.

Pace, N. and Rathbun, E. (1945) Studies on body composition. III. The body water and chemically combined nitrogen content in relation to fat content. *Journal of Biological Chemistry* **158**, 685-691.

Pichard, C., Kyle, U.G., Bracco, D., Slosman, D.O., Morabia, A. and Schutz, Y. (2000) Reference values of fat-free and fat masses by bioelectrical impedance analysis in 3393 healthy subjects. *Nutrition* **16**, 245-254.

Pierson, R.N., Jr., Wang, J., Heymsfield, S.B., Dilmanian, F.A. and Weber, D.A. (1990) High precision in-vivo neutron activation analysis: a new era for compartmental analysis in body composition. *Basic Life Science* **55**, 317-325.

Pietrobelli, A., Heymsfield, S.B., Wang, Z.M. and Gallagher, D. (2001) Multi-component body composition models: recent advances and future directions. *European Journal of Clinical Nutrition* **55**, 69-75.

Pietrobelli, A., Morini, P., Battistini, N., Chiumello, G., Nunez, C. and Heymsfield, S.B. (1998a) Appendicular skeletal muscle mass: prediction from multiple frequency segmental bioimpedance analysis. *European Journal of Clinical Nutrition* **52**, 507-511.

Pietrobelli, A., Wang, Z., Formica, C. and Heymsfield, S. B. (1998b) Dual-energy X-ray absorptiometry: fat estimation errors due to variation in soft tissue hydration. *American Journal of Physiology* **274**, E808-816.

Rankinen, T., Kim, S.Y., Perusse, L., Despres, J.P. and Bouchard, C. (1999) The prediction of abdominal visceral fat level from body composition and anthropometry: ROC analysis. *International Journal of Obesity and Related Metabolic Disorders* **23**, 801-809.

Rashid, M.N., Fuentes, F., Touchon, R.C. and Wehner, P.S. (2003) Obesity and the risk for cardiovascular disease. *Preventive Cardiology* **6**, 42-47.

Ross, R., Goodpaster, B., Kelley, D., and Boada, F. (2000) Magnetic resonance imaging in human body composition research. From quantitative to qualitative tissue measurement. *Annals of New York Academy of Science* **904**, 12-17.

Ross, R., Leger, L., Guardo, R., De Guise, J. and Pike, B. G. (1991) Adipose tissue volume measured by magnetic resonance imaging and computerized tomography in rats. *Journal of Applied Physiology* **70**, 2164-2172.

Ross, R., Leger, L., Morris, D., de Guise, J. and Guardo, R. (1992) Quantification of adipose tissue by MRI: relationship with anthropometric variables. *Journal of Applied Physiology* **72**, 787-795.

Rossner, S., Bo, W.J., Hiltbrandt, E., Hinson, W., Karstaedt, N., Santago, P., Sobol, W.T. and Crouse, J.R. (1990) Adipose tissue determinations in cadavers--a comparison between cross-sectional planimetry and computed tomography. *International Journal of Obesity and Related Metabolic Disorders* **14**, 893-902.

Seidell, J.C. and Flegal, K.M. (1997) Assessing obesity: classification and epidemiology. *British Medical Bulletin* **53**, 238-252.

Sievanen, H., Oja, P. and Vuori, I. (1994) Scanner-induced variability and quality assurance in longitudinal dual-energy x-ray absorptiometry measurements. *Medical Physics* **21**, 1795-1805.

Siri, W. (1956) The gross composition of the body. In: *Advances in biological and medical physics*. Ed: Lawrence, J. New York: Academic Press. pp. 239-280.

Slinde, F. and Rossander-Hulthen, L. (2001) Bioelectrical impedance: effect of 3 identical meals on diurnal impedance variation and calculation of body composition. *American Journal of Clinical Nutrition* **74**, 474-478.

Smith, S.R. and Ravussin, E. (2002) Emerging paradigms for understanding fatness and diabetes risk. *Curr Diab Rep* **2**, 223-230.

Tagliabue, A., Andreoli, A., Comelli, M., Bertoli, S., Testolin, G., Oriani, G. and De Lorenzo, A. (2001) Prediction of lean body mass from multifrequency segmental impedance: influence of adiposity. *Acta Diabetologica* **38**, 93-97.

Wagner, D.R. and Heyward, V.H. (1999) Techniques of body composition assessment: a review of laboratory and field methods. *Research Quarterly for Exercise and Sport* **70**, 135-149.

Wang, J., Thornton, J.C., Kolesnik, S. and Pierson, R.N., Jr. (2000) Anthropometry in body composition. An overview. *Annals of New York Academy of Science* **904**, 317-326.

Wang, Z., Deurenberg, P., Wang, W., Pietrobelli, A., Baumgartner, R.N. and Heymsfield, S.B. (1999) Hydration of fat-free body mass: review and critique of a classic body-composition constant. *American Journal of Clinical Nutrition* **69**, 833-841.

Wang, Z., Pi-Sunyer, F.X., Kotler, D.P., Wielopolski, L., Withers, R.T., Pierson, R.N., Jr. and Heymsfield, S.B. (2002) Multicomponent methods: evaluation of new and traditional soft tissue mineral models by in vivo neutron activation analysis. *American Journal of Clinical Nutrition* **76**, 968-974.

Wang, Z.M., Deurenberg, P., Guo, S.S., Pietrobelli, A., Wang, J., Pierson, R.N., Jr. and Heymsfield, S.B. (1998) Six-compartment body composition model: inter-method comparisons of total body fat measurement. *International Journal of Obesity and Related Metabolic Disorders* **22**, 329-337.

Wang, Z.M., Gallagher, D., Nelson, M.E., Matthews, D.E. and Heymsfield, S.B. (1996) Total-body skeletal muscle mass: evaluation of 24-h urinary creatinine excretion by computerized axial tomography. *American Journal of Clinical Nutrition* **63**, 863-869.

Wang, Z.M., Ma, R., Pierson, R.N., Jr. and Heymsfield, S.B. (1993) Five-level model: reconstruction of body weight at atomic, molecular, cellular, and tissue-system levels from neutron activation analysis. *Basic Life Science* **60**, 125-128.

Wang, Z.M., Pierson, R.N., Jr. and Heymsfield, S.B. (1992) The five-level model: a new approach to organizing body-composition research. *American Journal of Clinical Nutrition* **56**, 19-28.

WHO (2000) Obesity: preventing and managing the global epidemic. Report of a WHO consultation. *World Health Organ Tech Rep Ser*, World Health Organization, Geneva. pp. i-xii, 1-253.

Visscher, T.L., Seidell, J.C., Molarius, A., van der Kuip, D., Hofman, A. and Witteman, J.C. (2001) A comparison of body mass index, waist-hip ratio and waist circumference as predictors of all-cause mortality among the elderly: the Rotterdam study. *International Journal of Obesity and Related Metabolic Disorders* **25**, 1730-1735.

10. AUTHOR BIOGRAPHY

Jukka A. SALMI

Employment:
Researcher and PhD student, Department of Physiology, University of Kuopio, FIN

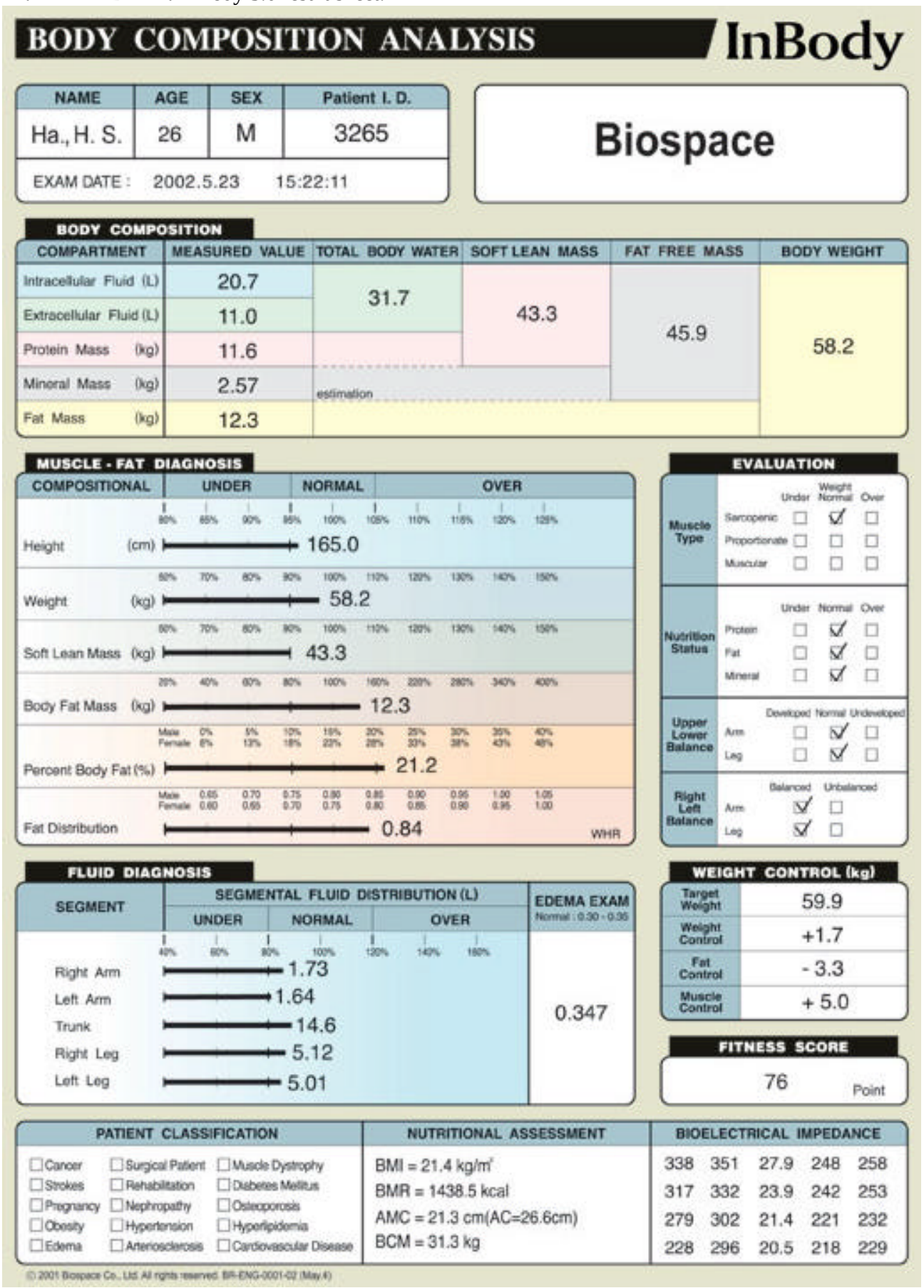
Degrees:
MSc Exercise Medicine, 2003. PhD student, 2002. MPH student, 2003. Dept. of Physiology and Dept. Public Health and General Practice, University of Kuopio, FIN.

Research interests:
Body composition assessment, Obesity, Physical activity

Email: jsalmi@hytti.uku.fi

✉ **Jukka A. Salmi**
Department of Physiology, University of Kuopio, 70211 Kuopio,Finkland

11. APPENDIX 1. InBody 3.0 result sheet.



BODY COMPOSITION ANALYSIS InBody

NAME	AGE	SEX	Patient I. D.
Ha., H. S.	26	M	3265

EXAM DATE : 2002.5.23 15:22:11

Biospace

BODY COMPOSITION

COMPARTMENT	MEASURED VALUE	TOTAL BODY WATER	SOFT LEAN MASS	FAT FREE MASS	BODY WEIGHT
Intracellular Fluid (L)	20.7	31.7	43.3	45.9	58.2
Extracellular Fluid (L)	11.0				
Protein Mass (kg)	11.6				
Mineral Mass (kg)	2.57	estimation			
Fat Mass (kg)	12.3				

MUSCLE - FAT DIAGNOSIS

COMPOSITIONAL	UNDER	NORMAL	OVER
Height (cm)		165.0	
Weight (kg)		58.2	
Soft Lean Mass (kg)		43.3	
Body Fat Mass (kg)		12.3	
Percent Body Fat (%)		21.2	
Fat Distribution		0.84 WHR	

EVALUATION

		Under	Normal	Over
Muscle Type	Sarcopenic	☐	☑	☐
	Proportionate	☐	☐	☐
	Muscular	☐	☐	☐
Nutrition Status	Protein	☐	☑	☐
	Fat	☐	☑	☐
	Mineral	☐	☑	☐

		Developed	Normal	Undeveloped
Upper Lower Balance	Arm	☐	☑	☐
	Leg	☐	☑	☐

		Balanced	Unbalanced
Right Left Balance	Arm	☑	☐
	Leg	☑	☐

FLUID DIAGNOSIS

SEGMENT	SEGMENTAL FLUID DISTRIBUTION (L) UNDER / NORMAL / OVER	EDEMA EXAM (Normal : 0.30 - 0.35)
Right Arm	1.73	0.347
Left Arm	1.64	
Trunk	14.6	
Right Leg	5.12	
Left Leg	5.01	

WEIGHT CONTROL (kg)

Target Weight	59.9
Weight Control	+1.7
Fat Control	- 3.3
Muscle Control	+ 5.0

FITNESS SCORE

76 Point

PATIENT CLASSIFICATION

☐ Cancer	☐ Surgical Patient	☐ Muscle Dystrophy
☐ Strokes	☐ Rehabilitation	☐ Diabetes Mellitus
☐ Pregnancy	☐ Nephropathy	☐ Osteoporosis
☐ Obesity	☐ Hypertension	☐ Hyperlipidemia
☐ Edema	☐ Arteriosclerosis	☐ Cardiovascular Disease

NUTRITIONAL ASSESSMENT

BMI = 21.4 kg/m²
BMR = 1438.5 kcal
AMC = 21.3 cm(AC=26.6cm)
BCM = 31.3 kg

BIOELECTRICAL IMPEDANCE

338	351	27.9	248	258
317	332	23.9	242	253
279	302	21.4	221	232
228	296	20.5	218	229