AN ANTHROPOMETRIC METHOD FOR FRACTIONATION OF SKIN, ADIPOSE, BONE, MUSCLE AND RESIDUAL TISSUE MASSES, IN MALES AND FEMALES AGE 6 TO 77 YEARS

by

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ABSTRACT

An anthropometric human body composition method was designed to predict skin, adipose, muscle, bone and residual tissue masses in males and females aged from 6 to 77 years. Based on departures from a defined unisex reference human the design of the method had two constraints: (1) the sum of the predicted fractional masses was to approximate the individual obtained body weight in 11 samples representing a wide variety of human physique and, (2) the individual tissue masses and the sum was to be consistent with anatomical evidence from the dissection of 12 male and 13 female human cadavers. When applied to all living subjects (n=1669) the standard error of estimate (SEE) for the prediction of body weight was 3.00kg and the correlation coefficient 0.987, with a tendency toward overprediction of the body mass by 1.6%. The SEE's for the samples ranged from 0.97kg for female lightweight rowers to 2.94kg for males age 6-17years. In 9 of the 11 samples the correlation coefficients ranged from 0.985 for girls aged 6-17 years to 0.931 for female university students. Male and female lightweight rowers showed the lowest correlation (0.608 and 0.509 respectively), indicative of the minimum variablity in their body weight. The sum of the predicted fractional tissue masses accounted for total body weight within 4% across all samples with the exception of body builders. An 8% error in this group was attributed to their extreme physique and possible dehydration at the time of measuring. The performance of the method, which was developed independently of the cadaver sample, was generally superior to other methods built and validated on the cadaver data. There exists potential for further refinement with computer optimization, augmented with medical imaging data and further cadaver evidence.

DEDICATION

To Jindrich Matiegka, in recognition of his legacy to the study of human physique.

> it was a major loss for students of human physique that Matiegka's approach, providing physical anthropometry with its vital "fourth dimension" remained for years unnoticed
>
> (Brozek, 1960).

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The emergence of kinanthropometry as a scientific discipline has been largely due to the cooperation and sharing of ideas and data, as well as the rigorous attention to technique. I have benefited from the work of the many scientists whose past and present works on the structure of human physique has enabled the completion of this thesis.

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I. CHAPTER 1 INTRODUCTION

> ...for nearly two centuries various distinguished men have studiously inquired into the rate of reproduction and mortality of mankind... but they have neglected to put forward with sufficient prominence the study of his physical development (*bodily growth*), and they have neglected to mark by numbers how individual man increases with respect to weight and height. (Quetelet, 1842)

1.1 HISTORICAL OVERVIEW

In any scientific discipline there must always be an impetus for growth. The study of human physique began as an art form in which the artists of the Renaissance period sought to reproduce the proportions of the human body. Throughout the Eighteenth and Nineteenth Centuries artists used the rules of bodily proportions defined by Jean Cousin (1520-1590) in his manual on portraiture and bodily proportions; a child is described as being five heads tall and an adult eight heads tall (Boyd, 1980). This in turn stimulated the anatomists to determine if there was a commonalty in the human form.

Adolphe Quetelet (1796-1874), the Belgium astronomer and mathematician was a progenitor in the study of body composition. Prompted by the social forces of the time he was instrumental in transforming the art form into a science by converging the new

discipline of statistics with what he had borrowed from art, an understanding of human geometry and proportionality.

> Quetelet had drawn the blueprint for the quantitative study of human growth that is in use today (Boyd, 1980).

From this blueprint evolved the many indices of height and weight. The best known of these is the ponderal index, which is also referred to as the Quetelet index (wt/ht^2). However, those that followed Quetelet found indices of height and weight inadequate for describing individual physique differences.

In 1921, Jendrich Matiegka published what is now a classical paper, "The testing of physical efficiency". Impetus for his original work arose from what he saw as the limitations of using a few anthropometric variables in an index, as in the case of the ponderal index. His proposed 4-component anthropometric system was "an original and potentially useful approach to the estimation of tissue masses on the basis of body measurements" (Brozek, 1961). Although several authors have acknowledged his work (Brozek 1961; Parizkova, 1977; Drinkwater and Ross, 1980), with the exception of Drinkwater and Ross (1980) and Behnke and Wilmore (1970) few have adopted Matiegka's approach to body composition analysis.

It was the 2-compartment model proposed by Behnke *et al.* (1942) that has had a greater impact on the field of body composition. Ironically, it was the the inadequacy of the indices of weight and height that also provided the impetus for this approach. Prompted by the need to determine body fat in football players classified as overweight by the standard height-weight tables, a densitometric approach was proposed.

The 2-compartment model was able to distinguish the fat and non-fat components of the body, which indices of height and weight were unable to do. Further stimulus to determine body fat was provided by the relationship between cardiovascular disease and

obesity. More recently, the need to delineate the parts of the fat-free compartment bone and muscle has become more apparent. Furthermore, the consistency of the fat and fat-free masses, a requirement of a 2-compartment system, is considered by many to be untenable (Werdein and Kyle, 1960; Siri, 1961; Martin, 1984; Ross *et al.*, 1987a).

> Empirical constants in fat estimating formulas may at best represent an average for a selected population (Siri, 1961).

The contribution of the 2-compartment model (Behnke *et al.*, 1942) to the area of body composition is monumental. However, although useful in practice as Roche (1984) has stated, it is "unrealistic and is in conflict with basic physiological and anatomical knowledge". New relationships need to be established that are consistent with the present *in vitro* and *in vivo* research and based on sound biological rationale.

Prompted by the limitations of the 2-compartment model, Drinkwater and Ross (1980) proposed a model to fractionate the body into skin-plus-adipose tissue, skeletal muscle, bone and residual tissue masses. This 4-compartment model was a merging of the ideas of Matiegka (1921) and the phantom stratagem of Ross and Wilson (1974). First reported in 1974, the PHANTOM wasused to describe proportionality characteristics of athletes and non-athletes. In a similar manner deviations in specific subsets of variables for the PHANTOM were used to predict the tissue masses of the 4 compartments. At the time, the only validation possible was well good the model could predict body weight in the living. In a sample of 939 subjects the model could predict body weight within 0.03%. However, what was not known was how accurate were the predictions of the component parts.

The Brussels cadaver study (Clarys *et al.*, 1984; Martin, 1984; Drinkwater, 1984; Marfell-Jones, 1984) provided comprehensive anthropometric data from 25 dissections and

allowed the validation of many indirect methods, including the methods of Matiegka (1921) and Drinkwater and Ross (1980). When applied to the Brussels cadaver data the prediction of the tissue masses by both methods was considered unacceptable (Drinkwater, 1984).

> The greatest merit a theoretical model can claim is that of being stated in clear enough terms so that it can be replaced, in part or *in toto*, by a new set of quantitative relationships, established by further research. (Brozek, 1965).

It was the purpose of this thesis to design a new method for the 5-way fractionation of the body mass, based on anthropometric deviations from a single reference human (PHANTOM). Thus, the proposed method is in the Matiegka tradition by fractionating the relevant tissue masses to test "physical efficiency" for scientific and professional purposes (Matiegka, 1921).

1.2 THE APPLICATIONS OF HUMAN BODY COMPOSITION ANALYSIS

A human body composition method based on anthropometry is considered advantageous over other approaches as it is non-invasive and inexpensive. It does, however, require strict attention to technique to maintain objectivity and reliability. More reliable methodologies are essential for all areas of body composition, as has been outlined in Table 1.1. However, there are specific areas where an anthropometric method that is able to estimate the relevant tissue masses has immediate application. These will be briefly summarized.

Sports Science

* *identify physique characteristics*
* *monitor training programs*
* *determine optimal muscularity and adiposity for weight class events*
* *assess nutritional adequacy when combined with dietary assessment*

Fitness & Employee Wellness Programs

* *monitoring of exercise and nutrition for individual assessment*
* *program evaluation*

Public Health

* *epidemiology of disease and body composition*
* *public education*
* *prevention of obesity as a cardiovascular risk factor*
* *new concepts of 'ideal' body weight*

Medicine

* *monitoring of dietary, surgical, pharmacological management of obesity*
* *longitudinal assessment of body composition changes with nutrition and dietary intervention*
* *identification of high risk patients and prevention of malnutrition through body composition assessment*
* *assessment and monitoring the recovery of anorexia nervosa and bulimia*
* *drug dosage and anaesthesia*
* *fluid balance*
* *assessment of the physically disabled*

Child Health

* *effects of genetic disorders on body composition*
* *provide normative data*
* *detection of atypical growth due to disease, eating disorders, malnutrition*
* *assessment of effects of physical activity on body composition*

Occupational Health

* *role in hypothermia and hyperthermia*
* *diving safety*
* *tissue specific poisoning*

Table 1.1: THE APPLICATIONS OF BODY COMPOSITION ANALYSIS (ADAPTED FROM MARTIN, 1984)

1.2.1 Sports Science

The appraisal of body composition can provide valuable information for both the athlete and coach in monitoring sequentially the influences of training and nutrition. The unique physique characteristics of an athlete can also be identified. An event can selectively reflect the "concomitant genetic and environmental influences of physique" (Ross and Ward, 1984).

In sports with specific weight categories, such as wrestling and lightweight rowing, weight fluctuations can be rapid, frequent and large (Brownell *et al.*, 1987; American College of Sports Medicine, 1976). Typically athletes will lose weight rapidly over a few days. This acute loss is composed of water, fat, protein and glycogen (Van Itallie & Young, 1977). Successive bouts of loss and gain in body weight may enhance food efficiency, which in turn leads to a slowing of weight loss and more rapid gains on overfeeding (Brownell *et al.*, 1986).

When transporting the body in the performance of physical activities where the body weight must be supported, excess adipose tissue is a burden (Buskirk and Mendez, 1984). Adipose tissue does not contribute to the movement and is considered a ballast substance (Tittel, 1978). By contrast, skeletal musculature provides the propulsive force to move the body. Thus for many athletes the ultimate goal is to minimize adiposity and maximize muscularity . In the process of losing body weight, it is not known how much of the muscle mass is compromised or if it is possible to increase the muscle mass during weight loss (Katch, 1984). Ideally, a technique to monitor change and evaluate status should be sensitive to differences in muscularity and adiposity.

1.2.2 Fitness & Employee Wellness Programs

The growth of corporate fitness programs has increased the need for a reliable and inexpensive method to appraise physique. Changes in body composition are common parameters used in evaluating a program's success (Brownell *et al.*, 1984). The present alternatives, the body mass index and percent body fat predictions, are unacceptable (refer to section 2.6, 2.7). Recent reviews by Ross *et al.* (1987a) and Martin (1984) have discussed the problems with the interpretation of these techniques.

1.2.3 Public Health

Epidemiological relationships between obesity and increased risk of cardiovascular disease are well established (Bray, 1986). Obesity carries with it a social stigma that places greater pressure on the individual to be 'thin'. However, the level of adiposity that constitutes an increased health risk in both males and females is unclear.

Regional distribution of adiposity is associated with metabolic complications of obesity (Bjorntorp, 1986). Excess adipose tissue is localized centrally in males and is associated with hyperinsulinemia, diabetes mellitus and hypertension (Bjorntorp 1986; Ducimetiere *et al.*, 1986). At comparable levels of adiposity women do not develop these complications, which is attributed to the differences in adipose tissue patterning between the sexes. In women, adiposity is localized in the femoral-gluteal region, whereas in men their adiposity is localized in the abdominal region (Bjorntorp, 1986). Further research into abdominal adiposity using computerized tomography appears promising (Enzi *et al.*, 1986).

A more appropriate concept than of 'ideal body weight' would be to establish the

nature of body composition optimal for health. As Garn (1986) has stated, "there is no single level of fatness ... that is ideal for all purposes, or with respect to all health risks".

1.2.4 Medicine

Documentation of malnutrition in hospital patients has focused on identifying the high risk patient with nutritional assessment. This encompasses anthropometric, dietary, clinical and biochemical assessment. In theory these parameters should reflect the status of the body cell mass components (Blackburn *et al.*, 1977); in practice, this is difficult to achieve. A decline in nutritional status is accompanied by delayed wound healing and greater susceptibility to infection (Butterworth, 1980). In addition, drug metabolism is altered and there is a decreased tolerance to radiotherapy and chemotherapy which places the patient at a higher risk of complications and increases the cost of hospitalization, much of which is avoidable.

The two general forms of adult malnutrition are marasmus and kwashiorkor (Butterworth and Weinsier, 1980). A third form is observed in hospitalized patients where acute metabolic stress is superimposed on the starvation state. Kwashiorkor results from protein deprivation. The acute onset results in a sharp decline in the visceral protein stores but prolongs the maintenance of the somatic stores. Thus for the detection of kwashiorkor anthropometry is of limited value as skeletal muscle and adipose reserves are maintianed. However in marasmus, or protein and energy starvation, the body utilizes fat and skeletal muscle and can be detected indirectly by anthropometric assessment. Edema, which is characteristic of prolonged malnutrition, masks the loss of body tissues (Keys *et al.*, 1950). Clinical features of marasmus in adults are; "starved appearance", weight to height ratio less than 80% of the standard, triceps skinfold less than 3mm and mid-arm circumference less than 15cm (Blackburn *et al.*, 1977). As a technique for detecting

nutritional depletion, this is an oversimplification that has serious ramifications for the patient.

Eating disorders, although recognized for centuries, have become increasingly prevalent (Strober, 1986). Typically, the individual with anorexia nervosa has a preoccupation with body shape and dieting behavior. Bulimia is characterized by binging and purging, usually with the maintenance of body weight within an acceptable range. In both disorders there is a dissatisfaction with body image which can be partly attributed to the social pressure towards thinness. The long term effects on body composition of eating disorders, particularly bone mineralization, have not been well established. In part this has been due to the problems inherent in body composition analysis.

Of particular concern are the surgical and dietary regimes that induce metabolic starvation. The effects of exercise on body composition during weight loss also warrant investigation. Evidence suggests that the lean body mass is preserved and adipose tissue stores are more effectively decreased when exercise is combined with dieting (Hill *et al.*, 1986). It is apparent that a method is needed to monitor the effects of the various dietary and surgical regimes on the component parts of the body.

1.2.5 Child health

The study of human growth and development is "an integral part of the scientific study of human biological structure, function and diversity" (Johnston, 1979). There are many techniques that have some validity in adult samples but few can be applied to monitoring the growth and development of children and adolescents (Malina, 1979a). For many techniques it is a question of when chemical maturity occurs as the constants used are applicable only to adults. Although for both sexes the growth spurt generally follows the same pattern, there are large individual variations in the timing and intensity of the

spurt (Hauspie, 1979). To quantify these differences analysis of longitudinal data becomes necessary.

Regular activity during growth may significantly affect the quantity and/or quality of fat and muscle tissues, bone mineral and aerobic function in adulthood (Malina, 1979b). Further research is needed to establish the optimal levels of activity for growth and development (Malina, 1979b).

1.2.6 Occupational health

The role of body composition in hypothermia and heat stress is not well established. However several investigators have alluded to factors that may be involved. Mittleman (1987) found the thermogenic response was independent of morphologies and fitness when subjects experienced a similar peripheral and central thermal stimulus. Accurate assessment of the tissue masses may elucidate further the response to heat stress and cooling on the human body.

The concept that adiposity may affect an individual's ability to withstand nitrogen narcosis was first made by Behnke *et al.* (1942) while studying army divers. Applying his 2-compartment model he reasoned that since nitrogen is fat soluble, as the level of adiposity increases the risk to the diver is also increased.

A non-invasive technique for estimating the tissue masses has application both for the researcher and clinician in delineating the role of body composition in occupational health.

The analysis of human body composition thus began as a quest for the ideal form by the neoclassical artists and emerged as a scientific discipline with the goals of improving health, optimizing performance and preventing disease.

The need for accurate estimation of body composition is well established. There is however, no 'ideal' method for determining the separate entities of the body; muscle, bone, and adipose tissue. The best method will depend on, "the end sought and the practical possibilities to measure" (Keys and Brozek, 1953).

1.3 DEFINITION OF TERMS

There are many ambiguities of terminology in the body composition literature. Hence for the purposes of this thesis the following definitions will be used, which are consistent with the definitions and anatomical terms of Drinkwater (1984).

Anatomical and anthropometric terms

1. **Predicted mass or mass --** used as a descriptive term only in referring to a predicted amount of a tissue or organ as determined by the 5-way fractionation method or other models.

2. **Predicted weight or weight --** used strictly to refer to a measured quantity of a tissue or organ as determined by cadaver dissection or by direct measurement for example, body weight.

3. **Tissue and organ masses --** the gross functional mass of a tissue, organ or organ system including all attendant nervous, vascular, and connective tissues. The organ or tissue masses considered are skin, adipose tissue, skeletal muscle, bone, and residual tissues (viscera and organs).

4. **Skin --** the anatomically dissectible mass of connective tissue, smooth muscle, some superficial striated muscle, hair, glands, associated adipose tissue, blood vessels with coagulated blood and nerves.

5. **Adipose tissue --** connective tissue, nerves and blood vessels with coagulated blood, small amounts of striated muscle as associated with overlying skin or underlying skeletal muscle.

6. **Muscle --** connective tissue including tendons and ligaments, nerves, blood vessels and coagulated blood, and an indeterminate amount of adipose tissue not physically separable from the muscle.

7. **Bone --** connective tissue including cartilage, periosteum, and muscle which could not be completely removed from the bone by scraping, nerves, blood vessels with coagulated blood, and attendant lipid contained in the medullary cavity.

8. Vital organs and viscera -- connective tissue, nerves, blood vessels with coagulated blood and adipose tissue which could not be physically dissected from the organs of the gastrointestinal tract; the viscera included the whole of the gastrointestinal tract excluding the tongue (which was considered part of the head muscle), the sex organs, remnants of the mesenteries, the bronchial tract not removed with the lungs, the great vessels not removed with the heart and all remaining tissues and fluids not otherwise accounted for.

9. Adiposity -- the total amount of adipose tissue present in the body, that is, the subcutaneous adipose tissue, the internal adipose tissue surrounding the organs, viscera and skeletal muscle.

10. Dissectible adipose tissue -- adipose tissue which is separable by gross dissection. This includes the bulk of the subcutaneous adipose tissue, adipose tissue surrounding organs and viscera, and very limited amount between muscle groups. Some subcutaneous adipose tissue will be included with the skin while an unknown but moderate quantity will remain with the organs, viscera and muscle.

11. Adipose-tissue-free mass -- the mass of the remaining tissue of the body after the removal of dissectible adipose tissue. This mass includes the lipids of non-dissectible adipose tissue, structural lipids, lipids of the nervous system, and bone lipids. This term is not equivalent to either "lipid-free mass" or "lean body mass".

12. Lipid -- ether extractable lipid. This includes triglycerides and free fatty acids extracted from adipose tissue, structural phospholipids from membranes and nervous tissues, lipids from bone marrow, and a small amount of other lipid based compounds in the body.

13. Essential lipid -- the total of the structural lipids of membranes, the nervous system, lipids of bone marrow and a small amount of other lipid based compounds in the body. Essential lipid is distinguished from more metabolically active "depot" lipids such as the triglycerides and free fatty acids of adipose tissue and muscle.

14. Fat -- is defined biochemically as ether extractable lipid which consists of adipose tissue and what are termed the essential lipids, the structural phospholipids of cell membranes and nervous tissues, lipids of bone marrow, and a small amount of other lipid based compounds. The term fat is commonly used in reference to the degree of obesity. The terms fat or fatness will not be used in this thesis, except in discussing the literature where percent body fat or fat has been used by authors.

15. Lean body mass -- the remaining mass of the tissue in the body after the removal of all lipid except the essential lipids of cell membranes, nervous tissue and bone marrow. This term is not equivalent to "adipose-tissue-free mass". The essential lipids are estimated to be between 3-7% of the body weight (Behnke and Wilmore, 1974).

16. Density -- the mass of the substance per unit volume.

17. Fractional mass -- used as a descriptive term only in referring to a predicted amount of a tissue or organ as determined by the 5-way fractionation method.

18. Phantom -- a conceptual unisex, bilaterally symmetrical model derived from reference male and female data and anatomical information, which allows the viewing of proportionality differences.

19. Z-score -- a dimensionally adjusted anthropometric item which is scaled to the PHANTOM stature (or other selected scaling factor) and expressed as the difference from the PHANTOM reference values.

20. Geometric model -- is a term used in reference to the model proposed by Drinkwater (1984). This model assumes the body to be bilaterally symmetrical and divisible into six regions: head & neck, trunk, two upper and two lower limbs, with each region comprised of one or more geometric solids consisting of concentric shells of tissues.

21. Regression model -- is a term used in reference to the regression equation proposed by Spenst (1986) for the anthropometric prediction of muscle mass in male subjects, which was developed from male cadaver data (Clarys *et al.*, 1984).

Statistical terms

22. Constant error -- (CE) is defined as the mean difference in the prediction of an obtained weight and a predicted mass and is defined as the mean of (P - O), where P is the predicted mass and O the obtained mass, expressed in the unit of measurement (usually kg). The CE is synonymous with systematic error or bias in the prediction of any weight. The %CE is defined as the mean of ((P-O)/O) * 100.

23. Standard error of estimate -- (SEE) defined as $SD(1 - r^2)^{0.5}$ where SD is the SD of the predicted variable and r is the correlation coefficient.

24. Total error -- (TE) combines the standard error of estimate and the constant error and is defined as: $((\text{sum } (P - O)^2) / n)^{0.5}$, where n is the sample size. The %TE is the total error expressed relative to the mean of the obtained weight ((TE/mean) * 100)

25. Spurious correlation -- a term used to describe a correlation coefficient obtained on the same sample used to develop the model.

26. Standard deviation -- is defined as the sum of the squared deviations devided by (n-1).

27. * -- is used to denote "multiplied by".

II. CHAPTER 2 REVIEW OF THE BODY COMPOSITION LITERATURE

2.1 ANALYSES OF BODY COMPOSITION

Body composition is evaluated by either direct (*in vitro*) or indirect (*in vivo*) methods. Direct chemical analysis and dissection of human cadavers provides theoretical validation for the indirect procedures (Widdowson *et al.*, 1951). It is by the indirect techniques however, that the structure of the human physique can be practically assessed.

2.2 DIRECT (IN VITRO) ESTIMATIONS OF BODY COMPOSITION

The infrequency with which cadaver dissections for the direct analysis of human body composition have been undertaken is an indication of the difficulties such studies present to even the most dedicated researchers. The earliest data on direct analysis are attributed to the work of German anatomists over 100 years ago (Keys and Brozek, 1953). Since 1940 only eight complete adult dissections (Mitchell *et al.*, 1945, Forbes *et al.*, 1953,

Widdowson *et al.* 1951, Moore *et al.*, 1968) had been carried out. Of these dissections, three did not have tissue weights reported, as chemical analysis only was performed.

The work by Clarys, Martin and Drinkwater (1984) added 25 completely dissected cadavers to the previous total of eight. The cadavers, sampled from an elderly Belgian population, were subjected to extensive measurements, including anthropometry, radiography, photogrammetry and densitometry; followed by dissection of each cadaver into the gross tissue masses of skin, adipose tissue, muscle, bone and organs. The normative data collected on the weights and densities of skin, adipose tissue, muscle, bone and organs cast doubts on the assumption of constant density of the fat-free mass (FFM). The data also formed the basis for the development of new models. While the relationship of measurement with the tissue weights and density can be determined it should be remembered that the data represent a small sample of cadavers and is not a normative data base.

2.3 INDIRECT (IN VIVO) ESTIMATIONS OF BODY COMPOSITION

In vivo research on body composition has centered on the quantification of body fat (Keys and Brozek, 1953). The focus on determining body fat is attributable to epidemiological evidence linking obesity with cardiovascular risk (Marks, 1960; Epstein *et al.*, 1965; Kannel *et al.*, 1967) and the ease with which subcutaneous adipose tissue can be readily measured with skinfold calipers. There is no satisfactory way to measure muscle and bone *in vivo* (Malina, 1979a). At best, reasonable estimates can be made.

Most of the techniques consider the body as a 2-component system, fat (FM) and fat-free mass (FFM). One component is measured directly (usually the fat mass) and the other (the FFM) is arrived at by subtraction (Keys and Brozek, 1953). A 2-component

system does not distinguish between the major portions of the FFM; muscle and bone are treated as constants. Water is also a constant 70-72% of the FFM (Behnke, 1963). Indirect derivation of each assumes a constancy of the FFM throughout adult life; this has been questioned (Werdein and Kyle, 1960; Durnin and Womersley, 1974; Martin, 1984; Ross *et al.*, 1987a). As stated by Garn (1963a) "in a biological system constants have a way of not being constant".

The division of the body mass into four compartments, fat, extracellular water, active tissue mass and bone mineral, is considered "metabolically reasonable" (Grande and Keys, 1978). The origins of this concept is from the work of Matiegka (1921) who used an anthropometric model to fractionate the body into four parts. Drinkwater and Ross (1980), extending Matiegka's concept, proposed a method for anthropometric estimation of adipose tissue, muscle, bone and residual tissues. Based on cadaver evidence Drinkwater (1984) used a similar approach for a geometric model of human body composition.

Comprehensive reviews of the body composition techniques have been made by Malina (1969), Keys and Brozek (1953), Lukaski (1987) and Brodie (1988a; 1988b). The literature reviewed will be limited to anthropometry . Densitometry will be reviewed as it is considered the criterion method for body composition analysis (Lohman, 1981).

2.4 DENSITOMETRY

2.4.1 The principle of density

Since the density of the body fat is less than other components of the body, the larger the proportion of fat, the lower will be the density of the whole body (Keys and Brozek, 1953). By application of Archimedes's principle, the volume of the body is determined from its displacement of water. The difference between the weight of the subject in air and the weight of the subject in water equals the weight of the displaced water. Thus, the volume of water can be calculated as the density of water at any temperature is known (Katch and Katch, 1984). To correct for the amount of air in the lungs, residual volume is measured and subtracted from the volume obtained under water (Keys and Brozek, 1953).

2.4.2 The measurement of density

Body density measures the proportionate contributions of fat and lean body weight to the body mass (Sinning, 1977). A two compartment model for the body is assumed in which density (D) is the weight (m) per unit of volume (v) and is expressed as

$$D(g/ml) = \text{mass (g)} / \text{volume (ml)}$$

The density of the body (D) can be then calculated from the following

$$D = \frac{Ma * Dw}{(Ma - Mw - V_R * Dw)}$$

where

D = density of the body
Ma = body mass (kg),
Mw = net underwater weight (kg),
Dw = correction factor for water density at the weighing temperature, and
V_R = residual volume (liters)
* denotes "multiplied by"
(Goldman and Buskirk, 1961).

There are two methods for the measurement of volume: volume displacement and underwater weighing (Sinning, 1977). With the volume displacement method, the displacement of the water is measured as the subject is immersed in water by a volumeter. Underwater weighing is based on Archimede's principle in which the immersed subject is buoyed by a force equal to the weight of the displaced water. Two practical problems should be considered:

(1) the subject must be able to remain submerged and motionless to enable an accurate measurement to be taken (Katch and Katch, 1984), and

(2) the water is also displaced by air trapped in the lungs and gut (Garrow, 1982).

Estimations of residual lung volume can be made by a nitrogen washout technique. However there is disagreement on how residual volume should be measured. According to Roche (1987) the choice does not appear to have substantial effects on the results. Intestinal gas has been estimated at between 30-100ml (Goldman and Buskirk, 1961).

There are however, individual differences (50-300ml) which may introduce error (Bedell *et al.*, 1956).

A new technique for measuring density, the plethysmograph, may be the most accurate method for estimating body fat (Garrow, 1982). This technique eliminates the need for the subject to be totally submerged and the measurement of residual volume.

2.4.3 Prediction of body fat from density

Fat extracted from adipose tissue has a density of 0.90 g/ml (Findanza, Keys and Anderson, 1953). From data in guinea pigs Rathburn and Pace (1945) estimated the density of the fat-free animal to be 1.090g/ml. Behnke *et al.* (1942) suggested the value of 1.099g/ml for the specific gravity of the human body which, is not the same as density. Keys and Brozek (1953) termed this value "a very rough arm-chair computation from old anatomical data". Assuming a two compartment model the percentage of fat in the body can be calculated from the following formula

$$F = \frac{1}{D} * \frac{d1d2}{(d2 - d1)} - \frac{d1}{(d2 - d1)}$$

where

D = density of the whole body
d_1 = density of fat
d_2 = density of lean tissue of FFM
(Keys and Brozek, 1953).

By applying the values d_1 = 0.900g/ml and d_2 = 1.100g/ml the equation becomes the commonly used equation of Siri (1956)

Percent body fat = 495 / D - 450 (Siri, 1956)

The accurate estimate of body fat from a single number substituted in an equation depends upon the degree of constancy of the density of fat and lean tissue (Keys and Brozek, 1953). Density differences in children, possibly due to hydration differences and lower bone densities, may give elevated estimates of body fat (Malina, 1979a). To accept that body fat can be predicted from densitometry requires the acceptance of the following assumptions , all of which have been questioned (Martin, 1984):

(1) the separate densities of the body components are additive

(2) the densities of the constituents of the body are constant from person to person, and

(3) an individual differs from a "standard reference man" only in the amount of adipose tissue he possesses.

2.4.4 Constancy of the fat density

The density of adult human body fat is relatively constant within and amongst individuals and is independent of age or sex (Wilmore, 1983). It is important to note that the constant of 0.900 g/ml is for ether extractable human lipid (Keys and Brozek, 1953).

Brain lipid has a density of 1.005, due to its composition of 50% phospholipid and 25% cholesterol (Thomas, 1962). As the total lipid in the brain amounts to about 200-300gms (Keys and Brozek, 1953) using 0.900 g/ml will not constitute a large source of error.

2.4.5 Constancy of the fat-free density.

The fat-free mass is the mass of remaining body tissues after ether extraction of all lipid, which includes lipids of adipose tissue, bone, nervous tissue and structural lipids from membranes (Drinkwater, 1984). For the density of the fat-free mass to be constant the following assumptions must be met (Martin, 1984):

(1) the components of the FFM (muscle, bone, skin and organs) do not vary between individuals, and

(2) each of the components must have constant densities.

Simply from knowledge of biological variability the first assumption stretches credulity. In four cadavers in which the composition of both the adipose-tissue-free mass (ATFM) and the FFM was known, the bone and muscle fractions showed a similar range in both the ATFM and the FFM (Martin, 1984). The ATFM consists of the whole body less all dissectible adipose tissue. Technically this is not the same as FFM. However, compositional changes in the ATFM should be reflected by changes also in the FFM. Evidence from 13 unembalmed cadavers showed a range in muscle content of 42.9-59.4%, bone from 16.3-25.7% and for the residual 24.0-32.4% (Martin, 1984). This provides strong support that wide individual variations also occur *in vivo*.

To assume that the density for the FFM is also constant appears even less credible. Cadaver evidence from Martin (1984) showed that individual densities for bone varied considerably. This is consistent with densitometric evidence of Jones and Corlett (1980), Their results indicate that discrepancies in the density of the FFM will occur due to ethnic, sex, age, and size differences, with the most significant density variation being due to differences in bone mineralization. Decreased bone density in osteoporosis will lead to overestimation of body fat (Werdein and Kyle, 1960). Alternatively, bone density is increased by physical activity, which would partly account for the negative estimates for %body fat obtained in professional football players (Adams *et al.*, 1982).

On reviewing the criterion methods for the measurement of body composition, Roche (1987) concludes on densitometry,

> although the present two-compartment equations to estimate body composition variables from body density are probably adequate for young white men, different equations are needed for females, for other ethnic groups, for different age groups and for those who are very active physically, because the groups differ in the density of fat-free mass.

2.5 THE ANTHROPOMETRIC ESTIMATION OF BODY COMPOSITION

Anthropometry is a technique of expressing quantitatively the dimensions of the human body, whether living or dead (Montagu, 1945). In his doctoral dissertation Johann Elsholtz (1623-1688) proposed the measuring of 42 heights, 19 widths and 18 girths to

differentiate between diseased and healthy people. He designed an "anthropometron" to assist in measuring the proportions of the human body and appears to have been the first to use the term anthropometry in its present day meaning (cited Boyd, 1980) but it wasn't until the publication of Quetelet's *Anthropometrica* (1870) that the word was used in the same context that it is today.

Anthropometric techniques can be administered rapidly and accurately by non-invasive procedures. According to Behnke (1963), the question of whether estimates of body components can be made from surface measurements depends on "unifying principles which render anthropometric data amenable to comparative analysis".

2.6. INDICES OF HEIGHT AND WEIGHT

The problem inherent to all indices of weight and height is that differentiation between obesity and ponderosity cannot be made (Ross *et al.*, 1987b). Body mass indices, derived from relationships between height and weight, are frequently included in epidemiological studies as estimates of body adiposity. The best known of these include the weight-height ratio W/H, Quetelet index W/H^2, Khosla-Lowe index W/H^3 and Benn index W/H^p (cited in Revicki and Israel, 1986). The indices may have application for detecting the incidence of obesity for groups but for the individual,

> body weight, even when evaluated with reference to the size of the skeleton, is a poor measurement of fatness. It is a very complex measure, with the same gross body weight representing in different individuals very different mixtures of the basic components-bone mineral, fat, extracellular fluid and 'cells'.
> (Keys and Brozek, 1953)

This was clearly demonstrated by Behnke *et al.* (1942). Of the 25 football players sampled, 17 would be classed as being 'overweight' by the simple weight for height tables and not physically qualified for the military.

2.6.1 The Quetelet Index

It was Quetelet's observation that the weight of adults of different heights is nearly as the square of stature, that is, weight/height^2 (Quetelet, 1842). For this relationship to be used as an index of obesity (the body mass index or BMI) was not Quetelet's intention. Garn (1986) states that it is "as much a measure of Lean Body Mass as it is a measure of fatness or obesity" and further adds that the BMI is not independent of stature, especially in children a view also supported by Ross *et al* (1987b).

For epidemiological studies the BMI has considerable support and has value for the identification of the risk factors associated with being overweight. For individuals, however, it is inadequate. In a sample of 177 young women, the correlation of the BMI with the sum of six skinfolds was 0.54, which is a predictive index of only about 16% better than chance (Ross *et al.*, 1987b).

2.7 PREDICTION OF BODY FAT AND MUSCLE MASS

The observation that anthropometric values were correlated with techniques such as densitometry, total body water and whole body counting has led to development of regression equations to predict body fat and the lean body mass (Johnston, 1982). Since 1950 more than 100 equations to predict body fat from skinfold measurements have been reported (Lohman, 1981). Similarly, equations have been developed for the estimation of muscle mass. The problem common to these equations is they are population specific (Johnston, 1982). The relationship between skinfold fat and body density appears to be quadratic, which would introduce error for the very lean or the obese individual (Jackson and Pollock, 1978). Six items of concern for the validity of prediction equations have been identified (Katch and Katch, 1980):

(1) bias due to lack of true random sampling

(2) prediction equations should accurately predict the mean of the criterion sample

(3) regression between the first prediction and the criterion should be linear

(4) the standard error of estimate, the constant error and the total error (mean of the squared deviations) should be considered

(5) for bias introduced by including a large number of independent variables r^2 should be corrected

(6) large sample sizes should be used ($n > 75$).

2.7.1 Skinfold caliper measurements

Approximately half of the body's adipose tissue is localized subcutaneously (Grande and Keys, 1980). A skinfold caliper reading is measuring the thickness of a double fold of skin and compressed subcutaneous tissue. To predict body fat from a skinfold caliper value requires the acceptance of certain assumptions (Martin, 1984) which are:

(1) constant compressibility

(2) skin thickness negligible or a constant fraction of skinfold

(3) fixed adipose tissue patterning

(4) constant fat fraction in adipose tissue

(5) fixed proportion of internal to external fat.

These assumptions were tested against cadaver data by Martin (1984). Variation in compressibility was considered to be the major problem, as compressibility showed large variations even within an individual cadaver. The compressibility at the skinfold sites, for the cadaver sample, ranged from 38.2-69.3%, with site differences also being demonstrated.

Caliper prediction of the adipose tissue mass rather than fat eliminates the wide variability in water content of adipose tissue. Further, it appears that the relationship between internal and external adipose tissue masses may be stronger than between internal and external fat (Martin, 1984).

Methodological factors also contribute to error in predicting body fat (Norgan and Ferro-Luzzi, 1985) and include

(1) technical error - measurement error from anthropometry or instruments used

(2) statistical factors
- small sample sizes with many independent variables
- failure to cross-validate formulated equations on other samples
- inappropriate methods for expressing data; for example linear equations for curvilinear relationships

Most prediction equations are population specific, which has prompted some researchers to develop generalized regression equations. These have been cross-validated in males (Jackson and Pollock, 1978) and females (Jackson *et al.*, 1980). However, Norgan and Ferro-Luzzi (1985) compared 5 generalized equations and found them to be statistically different, thus questioning the validity of generalized equations. Application of regression equations will result in large errors of prediction. Weltman and Katch (1978) were able to predict percent fat from densitometry within 6 % for adults. However, applying the same equation to children gave an error of 9 %, which was reduced by developing separate equations. Johnston concluded (1982)

> At present, it seems that human biologists are better off to continue to use anthropometry itself, rather than attempt to make estimates of whole-body composition from available equations. Even if such equations could provide usable estimates of mean parameters for samples, it seems clear that they are not sufficiently reliable for individual predictions.

2.7.2 Whole body conductivity

Methodologies based on the differing dielectrical properties of lean tissue and fat have received increasing attention (Segal *et al.*, 1985). Known as total body electrical conductivity (TOBEC) and bioelectrical impedance analysis (BIA), these methods have great appeal as they require minimal technical expertise and project a scientific aura.

Measurement of TOBEC depends on the principle that the lean tissue conducts electricity better than fat tissue (Harrison, 1987). The difference in electrolyte content between the FFM and the FM, permits the estimation of lean body mass from the magnitude of the body's electrical conductivity (Segal *et al.*, 1985). TOBEC is a uniform current induction method, whereas BIA is a localized injection method. In contrast, BIA measures the resistance to the flow of the current through the body (Harrison, 1987). Assuming that stature represents the length of the conductor and that resistance is an index of FFM then,

$$FFM = C * S^2 / R$$

where

S = stature
R = resistance and
C = constant (Guo *et al.*, 1987).

Fatness is derived for both methods by subtraction of the FFM from body mass.

Malina (1987), in an overview of the bieolectric methods fears a "proliferation of a new generation" of regression equations for the prediction of percent body fat and FFM. These equations suffer the same fate as other predictive equations; they are population specific. Whether changes in the electrolyte content of the body will also affect the

accuracy of BIA and TOBEC has yet to be evaluated. Dietary influences (for example. h'gh salt intake), dehydration, ethnic variation and the effects of disease states that influence electrolyte balance, should be documented before these procedures are widely applied (Malina, 1987). At present there is little evidence to support the use of either TOBEC or BIA for individual assessment of body composition.

2.7.3 The prediction of muscle mass

The selection of one or more anthropometric variables to derive muscle mass, is based on the assumption that local anthropometry reflects the regional muscle group. Also the mass of the muscle group, is assumed to be directly related to the total muscle mass and therefore the protein stores (Martin, 1984). Arm-muscle area derived from mid-upper arm circumference and triceps skinfold thickness, as originally proposed by Jeliffe (1979), relies on these assumptions.

Heymsfield *et al.* (1979) found that arm muscle area was overestimated by 15-25%. Gender specific equations reduced the predictive error for arm muscle area to approximately 8%. (Heymsfield *et al.*, 1982). These were:

$$cAMA = (MAC - (pi * TSF^2) / 4 * pi) - 10 \quad \text{for males}$$
$$cAMA = (MAC - (pi * TSF^2) / 4 * pi) - 6.5 \quad \text{for females}$$

where
cAMA = corrected arm muscle area (cm^2)
MAC = mid-upper-arm circumference (cm)
pi = 3.1416
TSF = triceps skinfold

It was further proposed that total muscle mass could be predicted from estimates for muscle derived from urinary creatinine excretion by the equation:

$$\text{muscle mass (kg)} = (\text{ht cm}^2) * (0.0264 + 0.0029 * \text{cAMA})$$

The error of prediction was between 5 and 9%. Spenst (1986) tested the equations of Heymsfield and Matiegka (see 2.8.1) on a male cadaver sample. The SEE as defined by Spenst was essentially the same as the total error (refer to 1.3). For the equation of Matiegka the SEE was 3.86 kg, whereas the SEE was 8.28kg for Heymsfield's (as shown above) estimation of total muscle mass. However, the best prediction was obtained with an equation developed on 6 unembalmed cadavers. The SEE, when this equation was tested in 6 embalmed male cadavers was 2.17kg (Spenst, 1986). The equation selected was

$$TMM = STAT\ (.058\ CTG + .11\ FG + .024\ CCG\ ) - 3000$$

where
TTM = total muscle mass
STAT = stretch stature
CTG = corrected mid-thigh girth
FG = forearm girth
CCG = corrected calf girth

Application of the equation *in vivo*, showed differences in muscle mass across a range of groups of varying activity levels. However, the predictability of the equation in women is yet to be established. As the regression equation was developed using only a very select group of male cadavers some specificity is likely. Also, with a high variables to subject ratio r approaches 1, as the number of independent variables entered in the regression equation approaches the number of subjects (Katch and Katch, 1984).

From cadaver evidence, the best anthropometric indicators of muscle mass for men and women, appears to be the forearm girth (Martin, 1984). For women, arm girth corrected for triceps skinfold was weakly correlated (0.484) to total muscle mass. The anthropometric variables selected for the prediction of muscle mass, should have some biological meaning and include enough variables to account for the overall muscle patterning (Martin, 1984).

2.7.4 Prediction of skeletal mass

The inacessability of bone makes the prediction of skeletal mass from anthropometry even more difficult than the prediction of muscle and adipose tissue. Thus, there exists no accurate method to determine the total bone mass (Malina, 1969). Regions where subcutaneous soft tissues are minimal, are the best sites for anthropometric values (Martin, 1984). The assumptions underlying the prediction of skeletal mass from anthropometric measurement of bone are:

(1) anthropometry accurately measures bone dimensions

(2) the shape of a particular bone does not change from one person to another and the bone density is constant

(3) the mass of the selected bone is a constant proportion of total skeletal mass (Martin, 1984).

In the Brussels study (Martin, 1984), density and size of bones were unrelated. However, bone density was related to age, with an estimated loss of 2% per decade. The best anthropometric indicator of skeletal mass for males and females was wrist breadth, followed by hand width and humerus width.

Martin also assessed the predictive accuracy of equations for skeletal mass by Matiegka (1921, see also 2.8.1), Alexander (1964) and von Dobeln (1964, refer to 2.8.3). The three equations overestimated bone mass on all cadavers. Despite the use of different anthropometric measures there was little difference between the predictions of Matiegka and von Dobeln.

2.8.1 *The method of Matiegka for the anthropometric estimation of anatomical body composition*

Matiegka (1921) introduced the concept of dividing the weight of the human body into 4 components: skin-plus-subcutaneous adipose tissue, skeletal muscle, bone and the remaining organs and viscera with each of the parts derived from anthropometry. The equations developed by Matiegka used groups of surface measurements that related closely to specific tissues. Using the limited cadaver data available, he derived a series of coefficients which related tissue weight estimates to surface measurements (Drinkwater *et al.*, 1985). He acknowledged that further cadaver evidence was required to validate the coefficients.

Some 60 years later Drinkwater *et al.* (1985), validated the equations against cadaver findings. Substantial errors were found when Matiegka's coefficients were used to predict skin-plus-subcutaneous adipose tissue and bone. New coefficients subsequently derived were more accurate. For individual predictions however, caution was recommended in using the equations. The authors concluded that the incorporation of the new coefficients into Matiegka's original equations could make reasonable estimates of bone and muscle in adults, whereas estimates of the remaining tissues were less certain. Matiegka's method is described in Table 2.1.

A statement by Brozek (1961) recognizes Matiegka's contribution to body composition analysis,

> While Matiegka was concerned with strengthening the practical usefulness of anthropological measurements, his ideas were of fundamental importance for quantitative human morphology in that he pointed to a new way for the synthesis of individual body measurements in a meaningful biological frame of reference and emphasized the fundamental role of body composition in describing man's physique.

Table 2.1 The method of Matiegka for the anthropometric estimation of the weights of: skin-plus-subcutaneous adipose tissue, muscle, bone and remaining tissues in the human body.

(1) Estimation of body weight

$$W = D + M + O + R$$

where

W = body weight (g)
D = skin + subcutaneous adipose tissue weight (g)
M = muscle weight (g)
O = skeletal weight (g)
R = residual weight (g), principally organs viscera and all other tissues and fluids not accounted for by the other three components

(2) Estimation of body (skeletal) weight

$$O = o^2 * L * k1$$

where:

O = skeletal weight (g)
o = (o1 + o2 + o3 + o4)/4, o1 to o4 being the maximal transverse diameter (cm) of the (o1) humeral and (o2) femoral condyles, (o3) wrist and (o4) ankle breadths measured on one side of the body
L = stature (cm)
k1 = 1.2

(3) Estimation of skin and subcutaneous adipose tissue weight

$$D = d * S * k2$$

where

D= skin plus subcutaneous adipose tissue weight (g)
d = 1/2 * (d1 + d2 + d3 + d4 + d5 + d6)/6,d1 to d6 being the thickness of skinfolds (mm) at the following sites:
(d1) upper arm above the biceps;
(d2) plantar side of the forearm at the level of maximum breadth;
(d3) thigh halfway between the inguinal fold and the knee above the quadriceps muscle;
(d4) calf of the leg at the maximum girth;
(d5) thorax halfway between the nipples and umbilicus on the costal margin; and on the costal margin;
(d6) abdomen halfway between the navel and anterior superior iliac spine.

S = surface area (DuBois and DuBois, 1916),
where, $S = 71.84 * W^{0.425} * L^{0.725}$ (cm^2)
k2 = 0.13

(4) Estimation of muscle weight

$$M = r^2 * L * k3$$

where:

M = skeletal muscle weight (g)
r = (r1 + r2+ r3+ r4)/4, r1 to r4 being the average radii (cm) of the extremities without skin and subcutaneous adipose tissue as determined from circumferences and skinfolds measured on
(r1) the flexed arm above the belly of the biceps;
(r2) the forearm at the maximum girth;
(r3) the thigh halfway between the trochanter and the lateral epicondyle of the femur;
(r4) the leg at the maximum calf girth
L = stature (cm)
k3 = 6.5

(5) Estimation of organs and viscera (residual) weight

$$R = W * k5$$

where:

R = the remainder or residual weight (the weight of organs, viscera and all other tissues or fluids not otherwise accounted for)
W = body weight (g)
k5 = 0.206

2.8.2 The methods of Behnke for the anthropometric estimation of total body weight and lean body weight

Behnke (1959) proposed a geometrical analogue, in which the body is represented by a series of stacked cylinders. Body weight is predicted "from the product of stature (h) and constant (K), and the squared sum of certain girth measurements and bideltoid diameter". Assuming the density of the body is 1.000g/ml, then weight is equated directly with volume. A model for determining lean body weight from anthropometric breadths and girths was correlated with body density and total body water (Behnke, 1959b). The methods of Behnke were evaluated by Drinkwater (1984). It was found that an accurate estimate of total body weight (within 5% for both sexes) could be obtained using the model. An estimate of lean body weight was about 24-28% more than the analogous adipose-tissue-free weight measured for the cadavers. Much of the difference might be accounted for by essential adipose tissue.

2.8.3 The method of von Dobeln for the estimation of skeletal weight

Von Dobeln (1964) predicted the weight of the skeleton from stature, and paired femur and wrist breadths. Skeletal weight was assumed to represent about 20% of adipose-tissue-free weight. The equation is as follows

$$\text{SKELETAL WEIGHT} = ((S/10)^2 * F * R * 100)^{0.712}$$

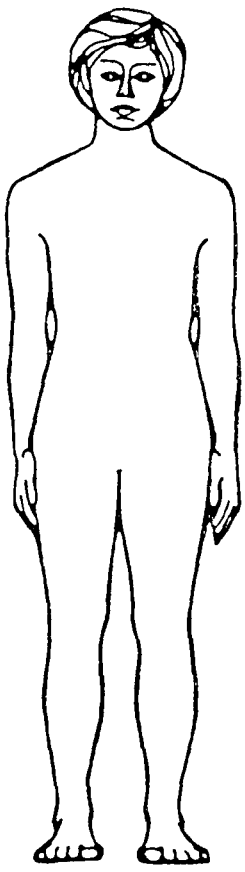
where

SKELETAL WEIGHT = estimated wet skeletal weight
S = stature (cm)
F = left + right femur breadth (cm)
R = left + right radio-ulnar breadth (cm)

When the equation was applied to cadaver data by Drinkwater (1984), it was found to overestimate bone weight by about 25%.

2.8.4 The method of Drinkwater and Ross for the anthropometric fractionation of the body mass

Drinkwater and Ross (1980), "picked up the challenge of Matiegka" and proposed a departure model for the anthropometric estimation of adipose tissue, skeletal muscle, bone and residual (organs plus viscera) tissue weights. The constants used by Matiegka were replaced by a variation of the proportionality stratagem described by Ross and Wilson (1974). The anthropometric values were geometrically scaled to a reference stature (170.18) and the scores compared with the hypothetical unisex human reference, the PHANTOM (Figure 2.1). Matiegka's original concept was extended to include a direct estimation of the residual mass, it was assumed that residual mass would vary directly with the volume of the trunk. Table 2.2 outlines the Drinkwater and Ross method for estimating the four tissue masses.



$$Z = \frac{1}{S}\left[V \left(\frac{170.18}{h}\right)^{d} - P \right]$$

Z is a proportionality score

S is the Phantom standard deviation for variable (V)

V is obtained value for variabile (V)

170.18 is the Phantom stature constant;
or, can be any proposed Phantom value
for use as a scaling constant

h is obtained stature;
or, the obtained value for the scaling constant

d is a dimensional exponent;
for a geometrical similarity system, d = 1 for lengths, breadths, girths, and skinfold thicknesses; 2 for all areas; 3 for all masses and volumes. Other theoretical similarity systems can supply d values (see Ross, et al., 1980, pp 7-8)

P is Phantom size for variable (V)

Figure 2.1 The PHANTOM: a single reference human

Table 2.2 The method of Drinkwater and Ross for the anthropometric estimation of the weights of adipose tissue, muscle, bone and residual tissues in the adult human body.

The fractionation tactic as applied to human subjects is based on the derivation of PHANTOM proportionality scores for selected measures using the general formula:

$$Z = 1/s * (V * (170.18 /h)^{d} - P)$$

where:

Z = PHANTOM proportionality score
V = any variable
d = a dimensional constant equal to 1 for lengths, breadths and girths; 2 for areas 3 for weights
h = measured stature (cm)
P = PHANTOM value for variable v (Ross and Ward, 1982)
s = PHANTOM standard deviation for variable v
170.18 = PHANTOM stature constant

The mean proportionality score (mean z-value) for each subset of measurements is then derived. This value is considered to be representative of the deviation from the phantom for the tissue characteristics of the subset, where

1. **Bone breadths** -- (group 1) predicts bone weight from biepicondylar humerus width, biepicondylar femur width, wrist girth and ankle girth

2. **Bone breadths** -- (group 2) predict residual weight from biacromial breadth, transverse chest, biiliocristal breadth, and anterior-posterior chest depth

3. **Skinfolds** -- predict adipose tissue weight from triceps skinfold, subscapular skinfold, abdominal skinfold, thigh skinfold and medial calf skinfold

4. **Skinfold corrected girths** -- predict muscle weight from upper arm girth (relaxed) corrected for triceps skinfold, chest girth corrected for subscapular skinfold, thigh girth corrected for front thigh skinfold and calf girth corrected for medial calf skinfold

The various tissue masses are calculated from the PHANTOM specified values using the following formula as follows

$$M = \frac{(Z * s + P)}{(170.18/h)^3}$$

where

M = any mass such as adipose tissue mass, skeletal mass, muscle mass, or residual mass
Z = the obtained mean PHANTOM proportionality score for the subset of measurements associated with a given tissue mass
P = specified PHANTOM value for the appropriate tissue mass
s = the specified PHANTOM standard deviation for that mass
h = obtained stature for the subject
3 = the dimensional exponent (since a geometric similarity system is assumed, and the cube of a linear measure is proportional to a volume or a mass of constant density, d is equal to 3)

The PHANTOM reference values are reported by Ross and Ward (1982). Total body weight (W.est) in kg, is estimated by summing each of the four components as follows

W.est. = adipose tissue + muscle + bone + residual

The estimated body weight can then be compared to the subject's obtained body weight.

The mean deviations of tissue-specific sets of anthropometric measurements were assumed to deviate in a similar manner from the PHANTOM tissue weights (Drinkwater, 1984). The hypothetical weights which are scaled to the PHANTOM stature, are rescaled with respect to the subject's original stature. This yields the true tissue weights for the subject. Unlike Matiegka's model, the weight of the four tissue masses was derived independently of the subject's body weight.

Application of the model to the Brussels cadaver data (Drinkwater, 1984), showed total body weight was underestimated by 6.3% and adipose tissue was severely underestimated (-51.6% for 13 unembalmed cadavers). Bone, muscle and residual were overestimated (+33.4%, +8.4%, +41.4%, respectively). Limitations of the method are:

(1) the method is dependent on the internal consistency of the PHANTOM model of Ross and Wilson (1974), and

(2) it does not account for differences in proportional lengths of various body parts.

For children then, who vary considerably from the adult form, the prediction of body weight is unacceptable.

A revised model based on the cadaver data resulted in an overall improvement in mean predictive accuracy for the sample. Drinkwater (1984) states, however that "as individuals increasingly deviate from the reference size and shape, the greater the error in predicting body weight of specific tissue masses". Hence, neither the original or the revised model is recommended for individuals or children.

2.8.5 A geometric model of human body composition

Drinkwater (1984) proposed a model that assumes the body to be "bilaterally symmetrical and divisible into six regions head and neck, trunk, two upper and two lower limbs". Essentially the entire body is represented by 10 truncated cones, with each cone comprised of shells of tissue as shown in Figure 2.2. The geometrical solids will over or under estimate the true volume, as body shape is not conical. To account for the deviation from the true volume, Drinkwater used specific scaling factors or volume "shape" coefficients derived from data on five cadavers. Using the known volume coefficient for any body part (an irregular solid), the true volume of the part could be estimated from the critical dimensions obtained on it.

The geometric model of the human body, as illustrated in Figure 2.3, shows each limb composed of two conic solids. But as tissue weights were known for the complete limb and not its segments, only one volume coefficient could be estimated for each tissue in the overall structure. Assuming bilateral symmetry, the upper limbs were considered as a single unit and similarly, for the lower limbs. Thus, for calculation the model was reduced to four regions: head and neck, trunk, upper and lower limbs. Tissue weights were also predicted using the appropriate density coefficient.

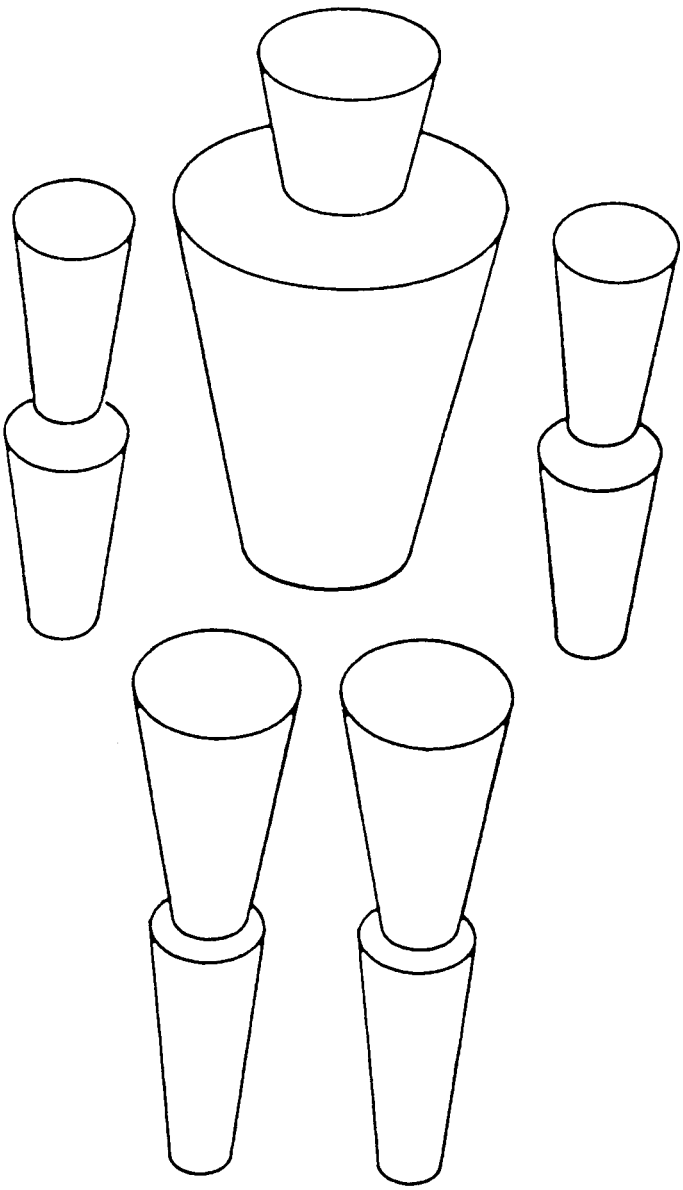


Figure 2.2 A geometric model of the human body

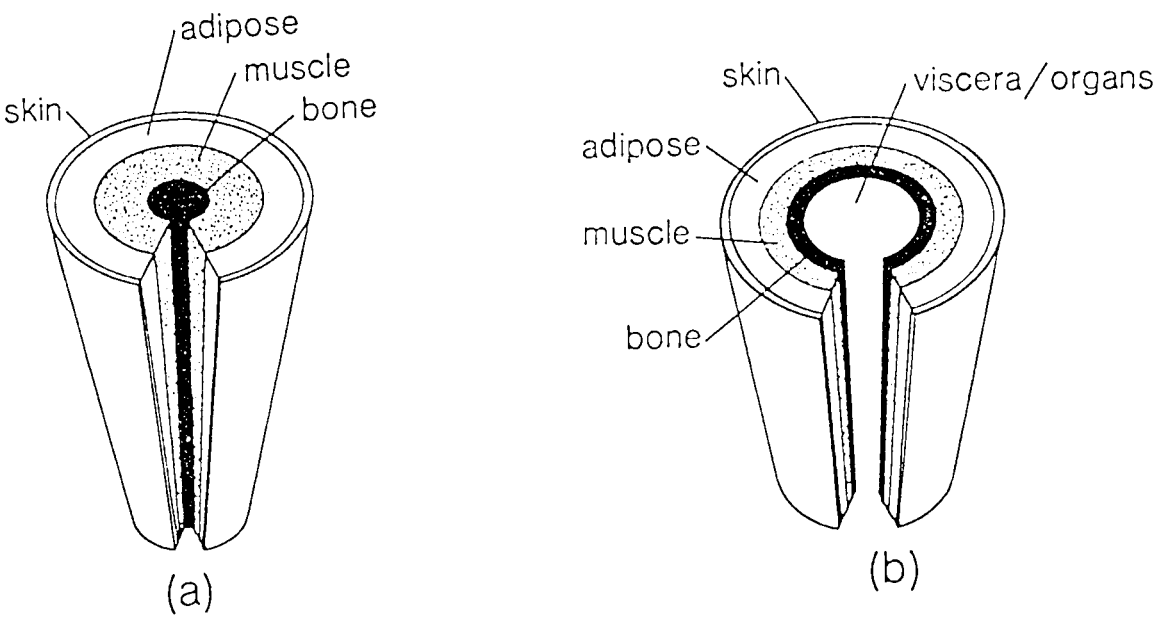


Figure 2.3 Body composition tissue models for the limbs (a) and for the head & neck and the trunk (b)

The volume coefficient is defined as: "the ratio of the volume of an irregular solid to the volume of a regular geometrical solid, whose bounds are defined by some critical dimensions (a specified length, breadth, and depth) of that irregular solid" (Drinkwater, 1984). The volume "shape" coefficient relates surface anthropometry to tissue volumes and weights. Derivation of the volume coefficients were from a sample of five embalmed and 5 unembalmed cadavers. The first volume derived were found to overestimate the true tissue volumes. Using all 20 cadavers, the volume coefficients were further adjusted. Although able to predict the obtained weights in 20 cadavers, for which there existed complete data on, half of the sample was used in the derivation of the volume coefficients and all 20 cadavers were used to adjust the final volume coefficients. Application of the model to living subjects indicates only how close is the estimation of body weight. There is no indication that the masses are predicted accurately. The model should demonstrate expected deviations in muscle and adipose tissue mass across the growth spurt and show differences across groups of varying adiposity and muscularity.

Drinkwater (1984) stated that the summation of all estimated tissue weights should closely approximate total body weight and this "serves as a form of face validity" for the model. This does not validate the estimation of individual tissue masses, which may be under or over estimated. Overall mean error was less than 4% and error variability less that 5%. Drinkwater concluded that the geometric model was able to reasonably predict body weight for subjects of varied physique and should be considered as an alternative method for the anthropometric estimation of human body composition.

The formulae for determining the volumes of the tissue cone and shell volumes volume coefficients tissue volume estimates and tissue weight estimates, are described briefly in Table 2.3. Proof for the proportionality theorem is reported by Drinkwater, 1984.

Table 2.3 Method for determining tissue volumes and weights using the geometric model of body composition

GENERAL FORMULAE FOR THE CALCULATIONS OF TISSUE SHELL VOLUMES

Each limb is considered to consist of truncated conic shells of skin, adipose tissue and muscle with a cylindrical core of bone. For the head/neck and trunk segments a core of organs and viscera is incorporated into the model.

The volume of the truncated cone is determined by the formula

$$V = 1/3 * L * (A + B + (A * B)^{0.5})$$

where

V = volume
L = length of the truncated cone
A,B = area of the bases A and B and can be determined from respective circumference

where

C = circumference of the cone
A = $C_A^2 / (4 * pi)$
B = $C_B^2 / (4 * pi)$
pi = 3.1416

VOLUME OF TISSUE CONE AND SHELL VOLUMES

Volume of the tissue shells as shown in Figure 2.2 can be determined by first calculating the total volume for each of the concentric truncated cones circumscribed by the outer circumference of a tissue shell then subtracting the volume of each of the cones from one another, using the formula below:

(1) calculation of concentric cone volumes

$$V_a = 1/3 * L * (A_a + B_a + (A_a * B_a)^{0.5})$$

where

V = the volume of the truncated cones
a = the respective cones from 1 to 5
A,B = areas of the bases of the cones
L = the length of the truncated cone

(2) calculation of tissue shell volumes

$$
\begin{aligned}
Vskin &= V1 - V2 \\
Vadip &= V2 - V3 \\
Vmusc &= V3 - V4 \\
Vbone &= V4 - V5 \\
Vresid &= V5
\end{aligned}
$$

where

residual is organs plus viscera, and
V_1 to V_5 are the volumes of the truncated cones 1 to 5, from skin to resdual

DETERMINATION OF VOLUME COEFFICIENTS

The volume coefficient is the ratio of the "true" volume of the tissue divided by the calculated volume of the tissue shell, thus

$$Ktiss = tru.Vtiss / Vshell$$

where

Ktiss	=	volume coefficient
tru.Vtiss	=	the true volume of a given tissue segment determined from the cadaver data
Vshell	=	the calculated volume of a given tissue shell in a segment from dimensions measured from the cadaver data

A separate volume coefficient is calculated for tissue shell volumes; skin, adipose, tissue, muscle, bone and residual.

ESTIMATION OF TISSUE VOLUMES FROM TISSUE SHELLS

The coefficients are then used to estimate the tissue volumes from any calculated tissue shell for any segment, thus

$$
\begin{aligned}
est.Vskin &= Ks * (V1 - V2) \\
est.Vadip &= Ka * (V2 - V3) \\
est.Vmusc &= Km * (V3 - V4) \\
est.Vbone &= Kb * (V4 - V5) \\
est.Vresid &= Kr * V5
\end{aligned}
$$

where

est.Vskin to est.Vresid = estimates of the true volumes of skin to residual tissues
Ks to Kr = volume coefficients determined from cadaver data
V1 to V5 = the tissue shell volumes cadaver determined dimensions

ESTIMATION OF TISSUE WEIGHTS

To estimate tissue weights, the tissue volume is multiplied by a density constant for each tissue, thus

$$est.W_a = estV_a * D_a$$

where

$est.W_a$ = the estimated weights for skin, adipose, muscle, bone and residual tissues, respectively

$est.V_a$ = estimated volumes of skin to residual tissues

D_a = the mean densities of skin to residual tissues for a given segment as determined from cadaver data

2.8.6 The O-Scale system

With the advent of the microcomputer, alternative approaches to body composition are now possible. The complexity of the program should not negate the need for precise measurement technique and must be founded on empirical evidence.

The O-scale microcomputer program is a professional system that requires a high degree of technical expertise in anthropometry (Ross *et al.*,1987a). Developed primarily for health and fitness professionals, the purpose of the system is to assist in making clinical judgments about the physique of the individual or of selected groups.

Unlike the geometric and regional proportionality models of Drinkwater (1984), it does not estimate the components of the body contributing to the total body mass; instead, an individual is compared to his or her same age and sex norm. The norms were constructed from a data bank of 1,236 children, youth and young adults (Ross *et al.*, 1980) and from a large data base of over 22,000 adults from an ongoing YMCA Lifestyle Inventory and Fitness Evaluation project (Bailey *et al.*, 1982).

To account for variability in adipose tissue patterning and dysplasia (Ross *et al.*, 1987), regional sampling of 6 skinfolds and 3 girths are used. In an updated version of the system, an expanded 22 item protocol incorporates additional skinfolds, girths and 2 bone breadths. Median values for the skinfolds and girths are used to calculate an A (adiposity) rating and a W (proportional weight) rating. The system uses percentile transformed standard score equivalents to establish standard nine or stanine categories.

For the ongoing monitoring of training and nutrition, the O-scale system is a useful professional decision-making tool. For group analysis statistical treatment is difficult. It is best suited to the assessment of an individual's physique and estimates of the fractional masses cannot be made.

In summary, with future innovations and research no doubt more definitive methodologies will evolve. As decisions relating to nutrition, growth, performance and medicine cannot await the resolving of controversies that abound in body composition analysis, alternative solutions must be sought. To date the best evidence is derived from direct cadaver dissections (Martin, 1984).

III. CHAPTER 3 RATIONALE

3.1 STATEMENT OF THE PROBLEM

The present methods for the anthropometric estimation of the human body do not have universal application and are unable to account for individual variation in five fractional tissue masses (skin, adipose, muscle, bone and residual organs).

3.2 JUSTIFICATION OF THE STUDY

The original Drinkwater and Ross model (1980) for estimating tissue weights, was a merging of the phantom stratagem (Ross and Wilson, 1974) and the original model of Matiegka (1921). Tissue masses were estimated using a system of proportionality assessment and a unisex human reference standard. It is assumed that the mean deviations of tissue-specific sets of anthropometric measurements reflect similar deviations in associated tissue masses. With a simple transformation to each individuals own height the predicted tissue mass is obtained. When applied to the Brussels cadaver data (Martin, 1984) the tissue masses were not accurately predicted, particularly for the adipose, bone

and residual tissues. Drinkwater revised the model by developing new specifications for a cadaver "phantom". This improved the prediction of bone and residual tissue weights, with respect to the mean % error and the % error variability. Drinkwater advised against using the model for individual predictions, but felt it may be adequate for group predictions.

Before any model is replaced the limitations of the model should be determined. Once established it "...can be replaced, in part or in toto, by a new set of quantitative relationships established by further research" (Brozek, 1965). The cadaver data has provided a rich data base for exploring new relationships between anthropometry and anatomical findings.

Thus, the limitations of a departure model have not been fully established. Predictions of the tissue masses in a cadaver sample and body weight *in vivo* may be improved by using a biological rationale for the selection of the anthropometric predictor variables; conforming more closely with the requirements of a geometrical similarity system; independent prediction of the mass of skin and; anatomically based phantom specifications.

The 5-way fractionation method was developed independently of the cadaver data and applied to the *in vivo* sample groups of divergent shape and size. Validation of the method was by application to the cadaver sample and divergent *in vivo* samples.

3.3 EXPERIMENTAL CONSTRAINTS

(1) the sum of the predicted fractional masses was to approximate the individual obtained body weight in 11 *in vivo* samples, representing a wide variety of human physique.

(2) the individual tissue masses and the sum was to be consistent with anatomical evidence from the dissection of 12 male and 13 female human cadavers.

3.4 CRITERION FOR TEST OF ADEQUACY

The criterion for adequacy of the proposed method was to compare the estimated masses as determined by the 5-way fractionation method with those derived by a geometric method (Drinkwater, 1984). If the fractionation method is unable to meet the constraints set the geometric method is accepted as the best model available at this time.

3.5 EXPERIMENTAL ASSUMPTIONS

(1) Anthropometric characteristics of each cadaver are not altered in death and can be extended to an *in vivo* model

(2) Anthropometry accurately measures the dimensions of skin, adipose, bone,muscle, and residual tissues

3.6 EXPERIMENTAL LIMITATIONS

The proposed revised model is dependent on the PHANTOM model of Ross and Wilson (1974) and the relationships between linear anthropometric measures and assigned tissue weight values (Drinkwater, 1984).

IV. CHAPTER 4 METHODS AND PROCEDURES

4.1 SUBJECTS

4.1.1. in vivo sample

Data assemblies on adults over a range of activity levels and age, as well as children were used to test the ability of the 5-way fractionation method to predict obtained body weight *in vivo*. Anthropometric data for these samples are as indicated on the anthropometric proforma of the Kinanthropometric Research Associates (Appendix A). All anthropometric values were obtained according to the protocol of Ross *et al.* (1987b).

CANAD: 95 male and 120 female university students aged from 18 to 35 years.

COGRO: COQUITLAM GROWTH STUDY - children 6 to 18 yrs, 447 boys and 425 girls, data collected from three schools in the Coquitlam School District of British Columbia (Whittingham, 1978)

MOGAP: MONTREAL OLYMPIC GAMES ANTHROPOLOGICAL PROJECT - 308 male and 148 female athletes from the Montreal Olympic Games, 1976, data collected by Carter, Hebbelinck, Ross (Carter *et al.*, 1976).

BBUILD: BODY BUILDERS REFERENCE SAMPLE - 66 male international class body builders, measured in Cairo, 1981 by W.D. Ross and J. Borms.

PANROW: LIGHT WEIGHT ROWERS REFERENCE SAMPLE - 20 male and 13 female lightweight rowers collected at the Pan American Games by S.M. Crawford and D.A. Kerr.

SCYCLE: SENIOR CYCLISTS SAMPLE - 18 male and 9 female cyclists aged 45-77 years. Data collected by S.M. Crawford and K. Mittleman (Mittleman, *et al.*, 1986)

4.1.2 Cadavers

Quantitative data of tissues and organs obtained from 25 human cadavers will be used to test the experimental hypotheses. The cadavers from the Brussels study (Martin, 1984) are comprised of 12 embalmed (6 males, 6 females) and 13 unembalmed (6 males, 7 females) with an age range at death of 55-94 years. The cadavers have been selected to include a range of morphological types. Cadavers showing evidence of prolonged immobility prior to death, severe emaciation, recent surgical intervention or death from infectious disease, were not used. A description of the cadavers is reported by Drinkwater (1984). The complete data base is shown in Appendix B. From a total of approximatley 450 anthropometric variables 12 items were missing. These missing values were estimated from regression equations in order to complete the data base.

4.2 EXPERIMENTAL DESIGN

4.2.1 Model Development

An anthropometric model for the 5-way fractionation of the body mass was based on departures from a single reference human (PHANTOM). The anthropometric parameters were selected in accordance with the following general rules

(1) The sampling of anthropometric variables should as far as possible, represent all regions of the body to account for the dysplasia of human structure and physique.

(2) Variables should be appropriate to the fractional mass being predicted, that is; body mass and stature predicts body surface and the mass of the skin, skinfolds predicts adipose tissue mass, corrected limb girths predict muscle mass, bone breadths predicts bone mass and trunk breadths and a trunk girth predicts residual mass.

(3) Account for proportional size differences by scaling to the appropriate length for example, residual mass will be scaled to the PHANTOM sitting height, head mass to head girth and all other masses to the stature of the PHANTOM.

(4) Adhere to the theoretical requirements of a geometric similarity system, which states that bodies of similar shape have volumes proportional to the cube of any linear dimension and therefore

W is proportional to L^3
H is proportional to L^1
G, B and S are all proportional to L^1 and

where

W = weight (body mass) in kg
H = height (stature) in cm
G = girths in cms
B = breadths and in cm
S = skinfolds in cm

(5) Anthropometric variables were selected from the proforma (Appendix A) to permit the application of the model to existing data bases.

The masses and regionally selected anthropometric indicators of the 5 tissue masses are shown in Table 4.1.

Table 4.1 The tissue masses and regionally selected anthropometric indicators

1. **Predict: skin --**

    *body weight
    *stature

2. **Predict: adipose tissue** -- skinfolds at 6 sites (2 per region)

    *triceps skinfold
    *subscapular skinfold
    *abdominal skinfold
    *supraspinale skinfold
    *front thigh skinfold
    *medial calf skinfold.

3. **Predict: muscle**-- skinfold corrected girths at 4 sites

    *relaxed arm girth corrected for triceps skinfold
    *forearm girth (uncorrected)
    *chest girth corrected for subscapular skinfold
    *thigh girth corrected for front thigh skinfold
    *calf girth corrected for medial calf skinfold.

4. **Predict: bone**-- bone breadths at 4 sites

    *biacromial breadth
    *biiliocristal breadth
    *biepicondylar humerus width
    *biepicondylar femur width.

    -- Head mass will be predicted from

    *head girth.

5. **Predict residual (organ and viscera)** -- skinfold corrected torso girth at 1 site and torso breadth and depth

    *waist girth corrected for abdominal skinfold
    *anterior-posterior chest depth
    *transverse chest breadth

Outlined in Table 4.2 is the rationale used in the selection of the anthropometric variables for each tissue mass. The method for the 5-way fractionation of the body mass is described in Table 4.3.

Table 4.2: Rationale for the selection of variables for each mass

1. **Skin**-- The prediction of skin mass is considered a function of the surface area of the body skin thickness and skin density. The cadaver data showed the obtained surface area to be higher in males than females. Preliminary investigations using the surface area formula of DuBois and DuBois (1916) suggested the constants were inappropriate for both males and females (see Table 5.6).Thus separate constants were derived for males and females. Skin thickness was estimated for males and females from the cadaver data by

   skin thickness = obtained skin mass/OBSA * OSD
   where OBSA = obtained body surface area
   OSD = obtained skin density

2. **Adipose Tissue**-- The criteria for the selection of skinfolds is to account for sex differences in which torso adiposity predominates in males and limb adiposity predominates in females, by sampling the regions of the body.

3. **Muscle**-- When considering a girth, the measurement will include components of bone, muscle, and subcutaneous adipose tissue. To account for the amount of subcutaneous adipose tissue present (Ross and Ward, 1982) it is necessary to adjust for the skinfold at the level of the girth. Thus, the size of the corrected girth is assumed to reflect the degree of muscular hypertrophy. To correct the girth the following equation is used (Ross and Ward, 1982)

   Fat-corrected Girth = Girth - (pi * Skinfold / 10)

   As forearm skinfold is not routinely taken, no correction is made.

4. **Bone**-- The biacromial and biiliocristal breadths are important measures to identify the shoulder-hip dimorphism of males and females (Ross and Ward,1982). To account for both limbs, the femur and humerus width is multiplied by a factor of two. Proportionately, children have a large head size compared with adults. If the bone mass of the head is scaled the height of the PHANTOM the bone mass will be disproportionately represented in children. Thus, the head mass is derived independently of the remaining skeletal mass; scaling to the PHANTOM head size.

5. **Residual Mass**-- The residual mass should be estimated by determining the volume of the chest cavity. As this volume is independent of limb length, the fractional mass is scaled to the length of the trunk (sitting height).

Table 4.3: The Anthropometric method for the 5-way fractionation of the body into skin, adipose tissue, muscle, bone and residual tissues in the human body.

1. Prediction of skin mass

To calculate the skin mass

$$M_s = SA * T_{sk} * 1.05$$

where:

M_s = skin mass in kg
SA = body surface area in m^2
1.05 = density of the skin (from cadaver data)
T_{sk} = thickness of the skin (from cadaver data) where, for males is 2.07 and females is 1.96

To calculate body surface area

$$SA = C_{SA} * W^{0.425} * H^{0.725}$$

where:

W = weight in kg
H = height in cm
SA = body surface area in m^2
C_{SA} = 68.308 in males age > 12 yrs
= 73.074 in females age > 12 yrs
= 70.691* in males and females < 12 yrs
* represents average of male and female constants

General formula for the prediction of adipose, muscle bone and residual tissue masses

The fractionation tactic requires a PHANTOM proportionality score be derived for each tissue mass according to the general formula:

$$Z = 1/s * (V * (C_p/C_s)^d - P)$$

where

Z = the PHANTOM proportionality score
V = sum of any variables
d = a dimensional constant equal to 1 for lengths, breadths and girths, 2 for areas, and 3 for weight
C_p = the PHANTOM scaling constant as designated (for example, height or sitting height).
C_s = is the measured variable for the scaling constant
P = the PHANTOM value for variable V
s = the PHANTOM standard deviation for variable V

The sum of the anthropometric scores for each subset of predictor variables (see Table 4.1) is used to determine a PHANTOM proportionality score for each tissue mass: adipose, muscle, bone and residual. Assigned PHANTOM tissue masses were iteratively selected from anatomical data summaries (Martin, 1984). The deviation from the PHANTOM value for each tissue mass is considered to represent the dysplasic characteristics of the tissue mass (Drinkwater 1984). Using the following formula, the fractional mass for each tissue is calculated

$$M = (Z * s + P) / (C_p/C_s)^3$$

where

M = any mass for example; adipose, tissue skeletal mass, muscle mass or residual mass
Z = the PHANTOM proportionality score for the subset of measurements associated with a given tissue mass
P = the specified PHANTOM value for the appropriate tissue mass
s = the specified PHANTOM standard deviation for the appropriate tissue mass
C_p = the PHANTOM scaling constant (generally height is used)
C_s = the obtained value for the scaling constant
3 = the dimensional exponent
(a geometric similarity system is assumed. Thus, the cube of a linear measure is proportional to a volume or a mass of constant density)

2. Prediction of adipose tissue mass

SFAT = sum (TPSF + SSSF + SISF + ABSF + THSF + MCSF) skinfolds
ZFAT = ((SFAT * (170.18/HT)) - 116.41) / 34.79

where 116.41 = phantom sum of skinfolds
34.79 = phantom sum of standard deviations for skinfolds
TPSF = tricep skinfold
SSSF = subscapular skinfold
SISF = supraspinale skinfold
ABSF = abdominal skinfold
THSF = front thigh skinfold
MCSF = medial calf skinfold

$$\text{ADIPOSE MASS (kg)} = \frac{((\text{ZFAT} * 5.85) + 25.6)}{(170.18/\text{HT})^3}$$

where 25.6 = phantom adipose mass (kg)
5.85 = phantom standard deviation for adipose

3. Prediction of bone mass

The bone mass of the head will be predicted by the following formula:

$$H_z = (1/s * V) - P$$

where
H_z = the PHANTOM score (unscaled) for head girth
s = the PHANTOM standard deviation for head girth
V = head girth in cm
P = the PHANTOM value for head girth

$$H_m = H_z * s + P$$

where:
H_m = head mass in kg
H_z = the PHANTOM score for head girth
s = the PHANTOM standard deviation for head mass
P = the specified PHANTOM value for head mass

The remaining skeletal mass is predicted according to the general method outlined above, thus

ZHEAD = (head girth - 56.0) / 1.44

where
56.0 = phantom head girth
1.44 = phantom standard deviation for head girth

BHEAD (kg) = (ZHEAD * 0.18) + 1.20

where,
1.20 = head bone mass
0.18 = SD of head bone mass

SBODY = sum (BIAC + BIIL + (2 * HUM) + (2 * FEM))

where
BIAC = biacromial breadth
BIIL = biiliocristal breath
HUM = humerus breath
FEM = femur breadth

ZBODY = (SBODY * (170.18/HT)) - 98.88 / 5.33

where
98.88 = phantom sum of bone breadths
5.33 = phantom sum of standard deviations for bone

$$BBODY\ (kg) = \frac{(ZBODY * 1.34) + 6.70}{(170.18/HT)^3}$$

where
6.70 = phantom body bone mass in kg
1.34 = phantom SD

TOTAL BONE MASS (kg) = BBODY + BHEAD

4. Prediction of muscle

SMU = sum (CAGR + FAG + CTHG + CCAG + CCHG)
ZMU = ((SMU * (170.18/HT) - 207.21) / 13.74

where
- 207.21 = phantom sum of corrected girths
- 13.74 = phantom sum of standard deviations for girths
- CAGR = arm girth (relaxed) corrected for triceps skinfold
- FAG = forearm girth
- CTHG = thigh girth corrected for front thigh skinfold
- CCAG = calf girth corrected for medial calf skinfold
- CCHG = chest girth corrected for subscapular skinfold

$$\text{MUSCLE (kg)} = \frac{((\text{ZMU} * 5.4) + 24.5)}{(170.18/\text{HT})^3}$$

where 24.5 = phantom muscle mass (kg)
5.4 = phantom standard deviation for muscle

5. Prediction of residual mass

SRES = sum (APCH + TRCH + CWAG)

where,
- APCH = anterior-posterior chest depth
- TRCH = transverse chest breadth
- CWAG = waist girth corrected for abdominal skinfold

ZRES = (SRES * (89.92/SITHT) - 109.35) / 7.08

where
- 89.92 = phantom sitting height
- 7.08 = phantom SD
- SITHT = sitting height

$$\text{RESIDUAL} = \frac{(\text{ZRES} * 1.24) + 6.10}{(89.92/\text{SITHT})^3}$$

where,
- 6.10 = phantom residual mass

1.24 = phantom standard deviation for residual mass

6. Prediction of total body mass

The predicted body mass is estimated by the sum of the five fractional tissue masses

$$\mathbf{M_T = (skin + adipose\ tissue + bone + muscle + residual)}$$

where

M_T = predicted body mass in kg

4.2.2 Accounting for total body weight in vivo

Obtained body weight was not used in either the original model of Drinkwater and Ross (1982) or the Geometric model (Drinkwater, 1984); except to determine the difference between the obtained body weight and predicted body mass. Close agreement of predicted body weight to obtained body weight provided "superficial validation" (Drinkwater, 1984) for the method. It cannot be determined however, how accurately the fractional masses are predicted *in vivo*. For the 5-way fractionation method is derived independently of the total body weight and of each mass, with the exception of in the derivation of surface area where body weight is used.

4.2.3 Validation of the 5-way fractionation method

Validity of the method was assessed in 2 ways:

1. The ability to explain body mass in 11 cross-sectional samples of divergent age and physique types and;

2. Consistency with anatomical evidence from 25 fully dissected human cadavers (Martin, 1984; Drinkwater, 1984).

4.2.4 Application of the 5-way fractionation method to in vivo

Introduction:

The concept of testing a model in groups of widely differing morphologies is not new and was first applied in the classic works of DuBois and DuBois (1916). In deriving the formula for body surface area, the subjects were of widely differing shape and size and included an infant, a child, a sculptor's model, an obese short man, an emaciated diabetic and 2 double amputees. When applied to the Brussels cadaver data (Martin, 1984), DuBois and DuBois' technique was found to be as accurate as any of the available formulae. As Martin (1984) concludes:

> it's success probably lies in the combination of two factors. First, it is derived from empirical data on subjects of very diverse shapes and sizes...Second, and perhaps more important, it adheres to the theoretical requirements of geometric similarity.

Application to divergent sample groups:

To test the 5-way fractionation method a similar approach to that of DuBois and DuBois (1916) was used; that is, the requirements of geometric similarity were adhered to and sample groups of widely differing shape and size were used.

Thus the method should predict total body weight equally well across all groups. Expected differences in the fractional masses should also be demonstrated; for example the muscle mass of body builders should be considerably greater than all other groups.

4.2.5 Application of the 5-way fractionatic n method to the cadaver sample

To determine how good the method can predict the obtained tissue weights of skin, adipose tissue, bone, muscle and residual mass the method was applied to the 25 human cadavers.

The predicted fractional tissue masses for the cadaver sample were summed to yield the predicted body mass. The predicted body mass and fractional masses were compared with the obtained weights, as determined by Martin *et al.* (1985).

4.3: STATISTICAL ANALYSES

The Statistical Package for the Social Sciences ($SPSS_x$) was used for all data analysis. The error in prediction of body weight *in vivo* and the obtained tissue weights in the cadaver sample was determined in accordance with the recommendations of Lohman (1981). The statistical terms are defined in section 1.3.

1. total error (TE) = $(\text{sum } (P - O)^2 / n)^{0.5}$ in kg

This includes two sources of error: lack of association between 2 sets of measurements (SEE) and; the extent of the mean differences between predicted (P) and obtained (O) values. As the sign is ignored, unlike the constant error, if values are overpredicted and underpredicted the error will not be cancelled out.

2. standard error of estimate (SEE) = $SD (1 - r^2)^{0.5}$ in kg where SD is the standard deviation of the predicted variable.

3. constant error (CE) = (P- O) in kg

The constant error is the mean difference between the predicted and obtained values and indicates the direction of the error. The percent constant error is reported, which expresses the error relative to the size of the tissue estimate.

V. CHAPTER 5 RESULTS AND DISCUSSION

The validity of the 5-way fractionation method essentially had two constraints,

(1) the sum of the predicted fractional masses was to approximate the individual obtained body weight in 11 *in vivo* samples, representing a wide variety of human physique.

(2) the individual tissue masses and the sum was to be consistent with anatomical evidence from the dissection of 12 male and 13 female human cadavers.

The test of adequacy for the method was to compare estimated masses of the fractionation method with those derived by the geometric model.

Despite the inherent spuriousness in the criterion method, no appreciable advantage over the proposed 5-way fractionation method was demonstrated, as presented in section 5.3. The first constraint will be addressed in section 5.1 and the second, in section 5.2.

5.1 THE IN VIVO PREDICTION OF BODY WEIGHT

Application of the 5-way fractionation method to all *in vivo* subjects (n=1669) aged 6 to 77 years, overestimated the total body weight by 1.6% (Table 5.1). The correlation coefficient (r) was 0.987 and the standard error of estimate (SEE) 3.00kg (Table 5.2). Thus, for the subjects sampled, the method was able to predict body weight within 3kg. The total error, which combines the SEE and the constant error, is also reported in Table 5.2.

ACCURACY OF PREDICTION OF BODY WEIGHT OF MEAN VALUES FOR THE 5-WAY FRACTIONATION MODEL APPLIED TO IN VIVO ANTHROPOMETRIC DATA ASSEMBLIES

			CONSTANT ERROR			
sample	sex	n	kg	(SD)	%	(%SD)
SCYCLE	M	18	-1.0	(3.0)	-1.6	(4.0)
	F	9	-0.1	(2.7)	-0.3	(4.4)
	ALL	27	-0.7	(2.9)	-1.2	(4.1)
CANAD	M	95	2.7	(3.4)	3.6	(4.2)
	F	120	1.7	(3.0)	3.0	(4.6)
	ALL	215	2.2	(3.2)	3.2	(4.4)
COGRO	M	447	1.0	(3.4)	1.6	(6.3)
	F	425	1.0	(2.8)	1.6	(5.5)
	ALL	872	1.0	(3.2)	1.6	(5.9)
BUILD	M	66	6.4	(2.4)	8.1	(3.0)
MOGAP	M	308	0.3	(2.8)	0.3	(3.6)
	F	148	-0.5	(2.5)	-0.9	(2.5)
	ALL	456	0.2	(2.7)	-0.1	(3.8)
PANROW	M	20	2.1	(2.1)	3.0	(3.0)
	F	13	0.7	(1.5)	1.1	(2.5)
	ALL	33	1.5	(2.0)	2.3	(2.9)
TOTAL	M	954	1.3	(3.5)	1.8	(5.4)
	F	715	0.8	(2.9)	1.3	(5.2)
	ALL	1669	1.1	(3.2)	1.6	(5.3)

Table 5.1 Mean differences between predicted body mass and obtained body weight (constant error=(P-O)) expressed in kg and as a percentage ((P-O)/O) * 100, by the 5-way fractionation method applied to data assemblies for:senior cyclists age 49-77 yrs (SCYCLE), university students age 18-35 yrs (CANAD), children age 6-17 yrs (COGRO), Montreal Olympic Games athletes (MOGAP), body builders (BUILD), Pan American games lightweight rowers (PANROW) and all in vivo subjects (TOTAL).

group	sex	n	r	r^2	SEE kg	TE kg
SCYCLE	M	18	0.963	0.928	2.46	3.07
	F	9	0.965	0.931	2.25	2.52
	ALL	27	0.965	0.931	2.53	2.90
CANAD	M	95	0.954	0.910	2.92	4.36
	F	120	0.931	0.867	2.86	3.46
	ALL	215	0.961	0.943	2.94	3.88
COGRO	M	447	0.983	0.966	2.94	3.58
	F	425	0.985	0.969	2.40	3.02
	ALL	872	0.984	0.968	2.69	3.32
BUILD	M	66	0.982	0.965	2.20	6.86
MOGAP	M	308	0.982	0.965	2.64	2.78
	F	148	0.963	0.928	2.31	2.52
	ALL	456	0.985	0.970	2.55	2.70
PANROW	M	20	0.608	0.370	1.35	2.96
	F	13	0.781	0.611	0.97	1.54
	ALL	33	0.965	0.932	1.63	2.50
TOTAL	M	954	0.987	0.974	3.23	3.74
	F	715	0.981	0.962	2.67	2.98
	ALL	1669	0.987	0.974	3.00	3.42

Table 5.2 The correlation coefficient (r), the standard error of estimate (SEE) in kg, and the total error (TE) in kg, for all in vivo samples., senior cyclists age 49-77 yrs (SCYCLE) university students age 18-35 yrs (CANAD), children age 6-17 yrs (COGRO), Montreal Olympic Games athletes (MOGAP), body builders (BUILD), Pan American Games lightweight rowers (PANROW) and all subjects (TOTAL).

As expected, there is an overall difference in the total body weight and the predicted body weight, between the sexes. The observed mean for the predicted body weight in males was 65.3kg and for females was 52.1kg. Analysis of covariance, controlling for sex, was performed to determine if the method was sex independent. When the means were adjusted to account for the sex effect, the difference between the predicted and obtained body weight was not significant (as shown in Table 5.3). Thus, indicating there was no sexual bias in the overall sample. When corrected for sex, as a covariant, the values for body weight were identical; 58.6kg for males and females.

source	SS	DF	MS	F	sig of F
within cell	16754.52	1666	10.04		
regression	522234.00	1	552234.00	54977.78	0.000
sex	0.01	1	0.01	00.0	0.974
total	538988.53	1669			

Table 5.3 Analysis of covariance as applied to all subjects controlling for sex

The correlations for the prediction of body weight for each sample group are shown in Table 5.2. The correlation coefficients and the SEE's were consistent across the groups, with the exception of the body builders and the lightweight rowers. The groups were selected to represent a wide range of morphology due to age, sex and level of activity. The consistency of the SEE (range 1.63-2.94kg) suggests the method is not sample specific. For group analysis across a range of activity levels and ages, the fractionation method has distinct advantages over the population specific methodologies.

As stated by Lohman (1981) the correlation coefficient by itself can be misleading. The SEE for small samples is a better indicator of the overall performance of the method. The low correlation for male and female lightweight rowers (Table 5.2) is indicative of the narrow range in body weight for the group (Fig. 5.1). In combining the two groups the range in body weight is increased and the correlation coefficient improved (0.965). The SEE is lowest in male and female lightweight rowers indicating that for individuals the prediction error is within 1.4kg for males and 1.0kg for females. Furthermore the constant error is in the direction of the weight classification, which is 72.5kg for male lightweight rowers and 59kg for the women. Dehydration at the time of measuring may have contributed to the overprediction of body weight as the rowers were striving to meet their weight class restriction.

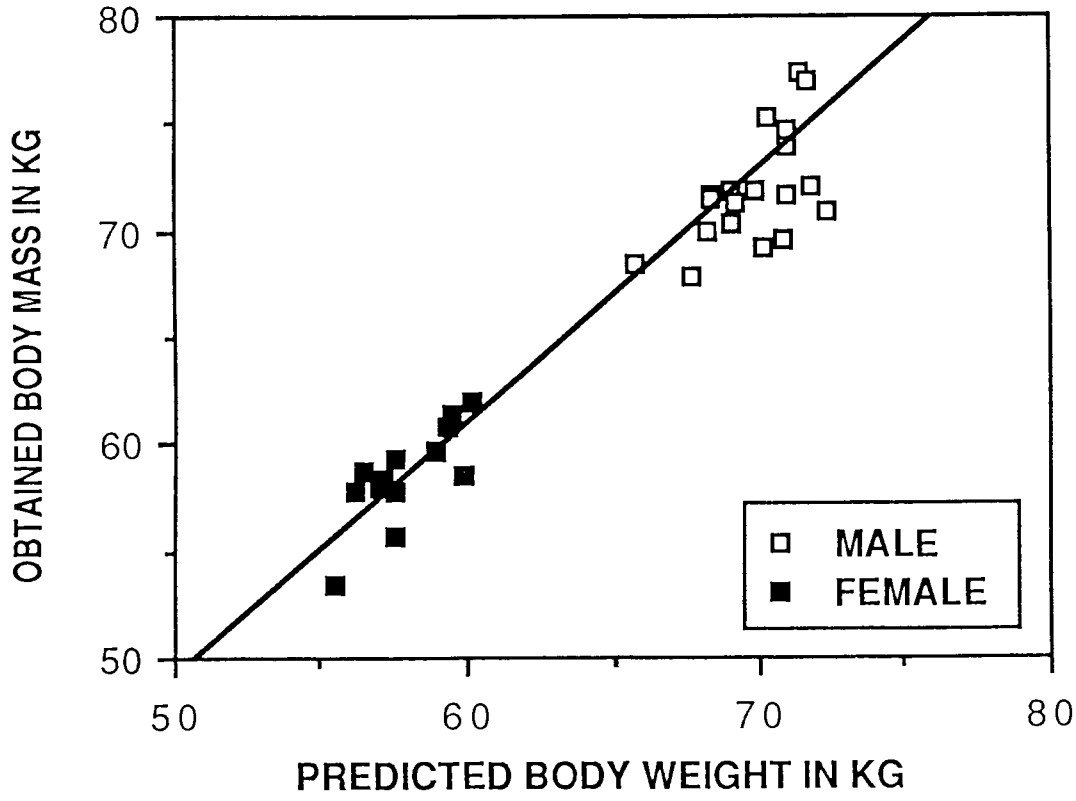


Figure 5.1 The predicted body mass, as determined by the 5-way fractionation method, in comparison to the obtained or actual body weight for male and female lightweight rowers

The method was least able to predict the body weight in the body builder sample. As shown by the constant error (8%) the method consistently overestimated body weight in this sample. The SEE was 2.20kg (Table 5.2) and within the range of all other samples. Similarly, the TE was also within the range of the other samples. Two conclusions can be drawn from this result. First, it serves to demonstrate that it is necessary to determine the CE, SEE and TE; the correlation coefficient itself is not an adequate indicator of prediction error (Katch and Katch, 1980; Lohman, 1981). Second, the constant error and the SEE indicates a systematic error in prediction. The direction of the constant error suggest that level of hydration may be a factor. Dehydrate prior to competition to meet the weight class and enhance the aesthetic muscle definition is a common practice amongst body builders. Diuretics are used by many athletes, including body builders, when attempting to "make weight" (Caldwell, 1987).

Although not well documented in body builders, evidence from other weight class sports provide an indication of the level of dehydration possible. In wrestling, dehydrating prior to competition is a common practice (American College of Sports Medicine, 1979). A wrestler monitored for two months before a national competition (Widerman and Hagan, 1982) was able to lose 2.73kg by dehydration on the day prior to competition. A decreased plasma volume that accompanies dehydration (American College of Sports Medicine, 1979) would not be accounted for in the fractionation model. The prediction of residual mass, which is derived from anterior-posterior chest depth, transverse chest breadth and the corrected waist girth would not be altered appreciably by dehydration.

According to Drinkwater (1984) the prediction of body weight with a proportionality model results in close approximation when the individual most closely approximates the PHANTOM model. As individuals deviate in size and shape from the PHANTOM the error in estimating body and tissue weights is increased. The original proportionality model (refer to section 2.8.4) overestimated body weight in children by 5.4% (SD 6.6) and was therefore not recommended for use in children. The 5-way fractionation method was able to predict the body weight of children from the COGRO sample within 2%; with a TE of less that 4kg, which indicates a marked improvement in prediction with the 5-way fractionation approach. The total error when expressed relative to the body weight for each age and sex, ranged from the lowest %TE for males aged 16 yrs (%TE 4.0) to the highest, at age 11 for both males and females (%TE 10.9 and 14.2 respectively). Generally the % total error was consistent across the age range and between the sexes. This indicates that the method can be applied to the assessment of the tissue masses in children of varying age categories.

Application of the method to longitudinal data would assess the sensitivity of the model to monitoring change. However, in the absence of such data, application of the method to the COGRO mean values for the prediction of percent muscle and adipose tissue mass the expected deviations across the ages are demonstrated (see Fig 5.2 and Fig 5.3). Evidence suggests that the changes in the FFM that occur during growth are due to changes in the the muscle and bone mineral content, which change the water, mineral and potassium content of the FFM. Hence, the inherent limitation of the 2-compartment model is that it requires the use of age- and sex-specific constants (Lohman, 1986). Even with the derivation of separate equations for predicting body fat in prepubescent, pubescent and postpubescent subjects the use will be limited to each subsample. Haschke (1983)

estimated the FM and the FFM of a reference male adolescent between 10.5 to 18.5 years with age and sex-specific constants and demonstrated an increase in fatness between 10 and 11.5 years of age, followed by a gradual decline. Although body fat is not completely analogous to the anatomically defined adipose tissue mass, the relative deviation in body fat when age and sex-specific constants were used appears corroboratory with the fractionated adipose tissue mass.

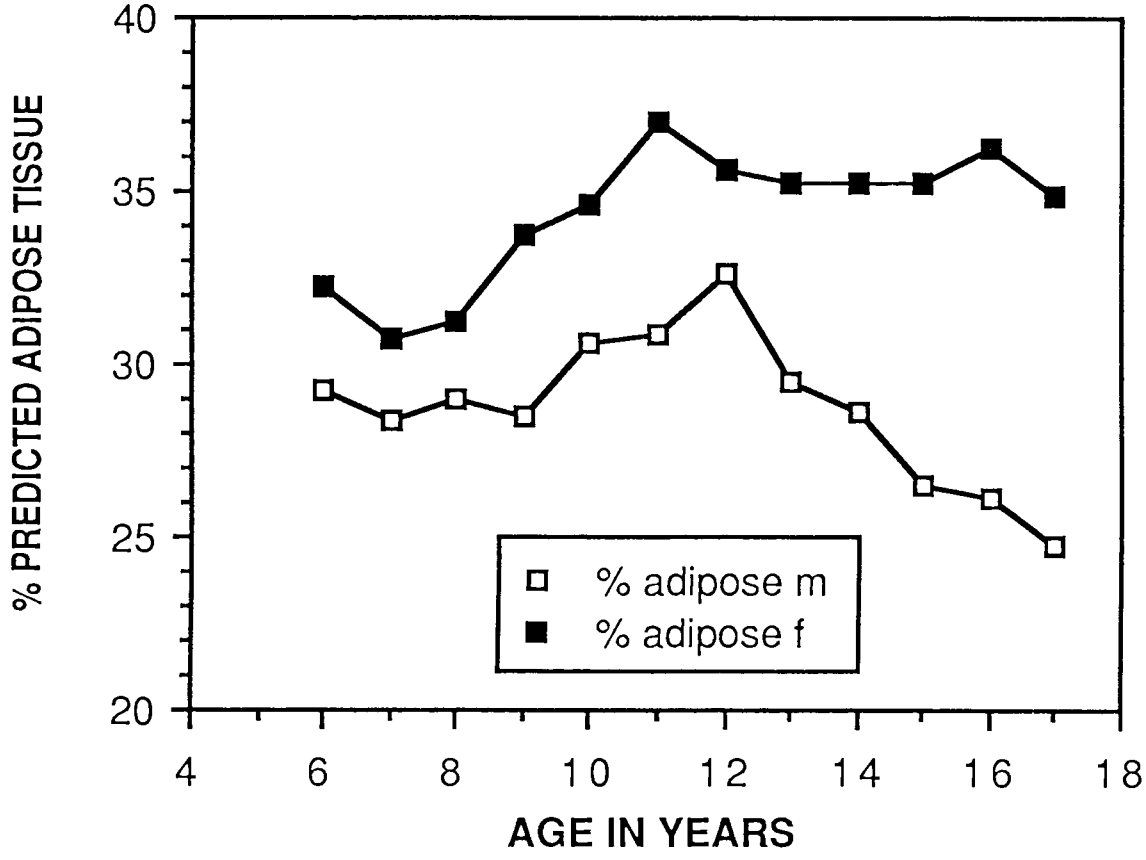


Figure 5.2 Application of the 5-way fractionation method for the prediction of percentage adipose tissue mass to the Coquitlam growth study (COGRO) a cross-sectional study of males and females aaged 6-17 years

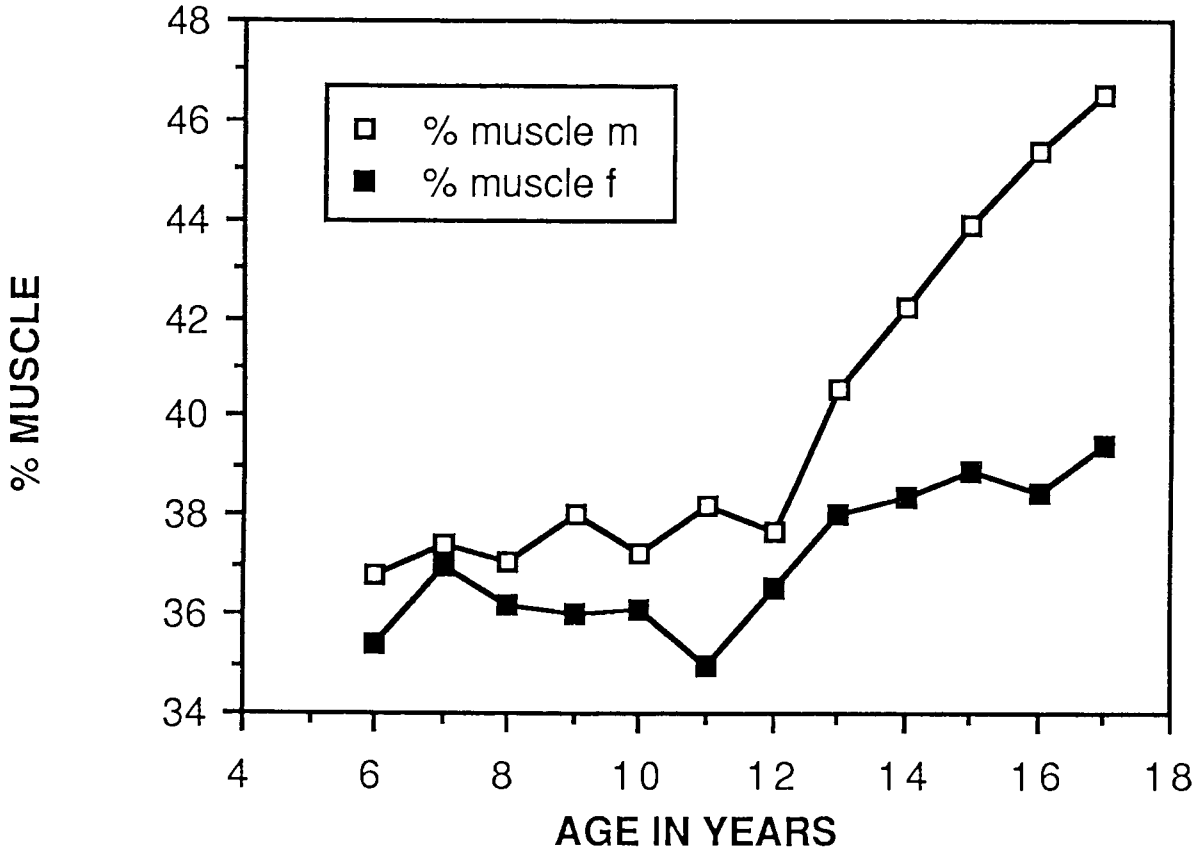


Figure 5.3 Application of the 5-way fractionation method for the prediction of percentage muscle mass to the Coquitlam growth study (COGRO) a cross-sectional study of males and females aaged 6-17 years

Underestimation of body weight in both the senior cyclists and the cadaver sample (Table 5.4) suggests the error may be related to the aging process. Comparison of the two groups shows the prediction of the percentage fractional masses similar in the males and females of both groups as shown in Table 5.4. As expected, the senior cyclists have a higher percentage muscle and lower predicted percentage adiposity. With advancing age adiposity is known to be internalized (Borkan *et al*, 1983), which is not sampled by a skinfold caliper reading. Also, there is a loss of bone density with aging in both sexes but occurs to a greater extent in females (Mazess, 1982). Skinfold compressibility also increases with aging, which would underestimate adiposity. These factors related to the aging process may account for the underprediction of total body weight in the senior cyclists.

FRACTIONAL MASS ESTIMATES APPLIED TO CADAVER AND SENIOR CYCLISTS DATA ASSEMBLIES

		CADAVER			SENIOR CYCLISTS		
TISSUE	SEX	n	% MASS	(%SD)	n	% MASS	(%SD)
SKIN							
	M	12	5.5	(0.5)	18	5.5	(0.5)
	F	13	5.5	(0.5)	9	5.6	(0.5)
	ALL	25	5.5	(0.5)	27	5.6	(0.5)
ADIPOSE							
	M	12	29.2	(5.3)	18	23.8	(3.2)
	F	13	38.2	(6.4)	9	36.4	(5.1)
	ALL	25	33.9	(7.3)	27	28.0	(7.2)
MUSCLE							
	M	12	37.0	(4.8)	18	44.2	(2.2)
	F	13	28.2	(4.9)	9	35.7	(3.4)
	ALL	25	32.4	(6.5)	27	41.3	(4.8)
BONE							
	M	12	13.2	(1.6)	18	12.5	(1.3)
	F	13	13.0	(1.9)	9	12.5	(1.5)
	ALL	25	13.1	(1.7)	27	12.5	(1.4)
RESIDUAL							
	M	12	14.5	(1.6)	18	14.0	(1.1)
	F	13	12.1	(1.5)	9	9.8	(0.9)
	ALL	25	13.3	(1.9)	27	12.6	(2.3)

Table 5.4 Predicted tissue masses expressed as a percentage of the total body weight (% standard deviation) by the 5-way fraction model for all male and female cadavers, Brussels cadaver study and senior cyclists.

Performance of the 5-way fractionation method was satisfactory in most groups (CE < 4%). With the exception of the body builders, who represent an extreme physique type, the method is recommended for group assessment.

5.2 PREDICTION OF THE FRACTIONAL TISSUE MASSES IN THE CADAVER SAMPLE

5.2.1 Prediction of body weight in the cadaver sample

The constant error in predicting body weight for 25 cadavers is shown in Table 5.5. Body weight was underestimated in both sexes by approximately 2% (SD 4.5) but to a greater extent in the female cadavers (-3.0%) than the males (-0.4%). As shown in Table 5.6, the TE in predicting body weight for the 25 cadavers was 3.16 kg, with females demonstrating a higher TE (3.79 kg) than males (TE 2.27 kg).

ACCURACY OF ANTHROPOMETRIC PREDICTION OF TISSUE WEIGHTS BY THE 5-WAY FRACTIONATION METHOD APPLIED TO A CADAVER DATA ASSEMBLY

			PRED MASS		OBT WT		CONSTANT		ERROR		2-tail
tissue	sex	n	kg	(SD)	kg	(SD)	kg	(SD)	%	(%SD)	prob.
SKIN											
	M	12	3.6	(0.9)	3.7	(0.4)	0.1	(0.6)	1.6	(17.0)	0.580
	F	13	3.4	(0.3)	3.4	(0.4)	0.1	(0.4)	2.2	(12.0)	0.643
	ALL	25	3.5	(0.3)	3.5	(0.7)	-0.0	(0.5)	1.9	(14.3)	0.851
ADIPOSE											
	M	12	19.2	(4.1)	18.5	(4.6)	0.7	(2.1)	5.8	(13.7)	0.269
	F	13	23.8	(5.0)	25.8	(7.8)	-2.0	(5.1)	-3.6	(21.2)	0.194
	ALL	25	21.6	(5.1)	22.3	(7.3)	-0.7	(4.1)	0.9	(18.3)	0.423
MUSCLE											
	M	12	24.8	(6.9)	25.1	(7.4)	-0.3	(2.3)	-0.7	(9.8	0.632
	F	13	17.6	(4.0)	17.7	(3.0)	-0.1	(2.3)	-1.2	(13.8)	0.830
	ALL	25	21.1	(6.6)	21.3	(6.6)	-0.2	(2.3)	-1.0	(11.8)	0.616
BONE											
	M	12	8.7	(1.3)	9.3	(1.4)	-0.6	(0.8)	-6.7	(8.7)	0.018*
	F	13	8.0	(0.7)	7.7	(0.8)	0.3	(0.6)	3.7	(8.2)	0.165
	ALL	25	8.3	(1.1)	8.5	(1.4)	-0.2	(0.8)	-1.3	(9.8)	0.290
RESIDUAL											
	M	12	9.5	(1.4)	9.5	(1.4)	0.0	(1.2)	0.6	(12.2)	0.965
	F	13	7.6	(1.6)	7.8	(1.3)	-0.2	(1.4)	-1.6	(18.3)	0.639
	ALL	25	8.5	(1.8)	8.6	(1.6)	-0.1	(1.3)	-0.6	(15.4)	0.683
BODY WEIGHT											
	M	12	65.8	(12.0)	66.2	(12.5)	-0.4	(2.3)	-0.5	(3.5.)	0.559
	F	13	60.4	(8.3)	62.5	(9.4)	-2.1	(3.3)	-3.0	(5.0)	0.047*
	ALL	25	63.0	(10.0)	64.3	(10.9)	-1.3	(3.0)	-1.8	(4.5)	0.044*

Table 5.5 The constant error (P-O) in kg and expressed as a percentage constant error of the obtained tissue weight (OBT WT) for the prediction of skin, adipose, muscle, bone, residual and body mass by the 5-way fractionation method applied to male and female cadavers.

* significantly different from the obtained weight (at 5% level) $p<0.05$

tissue	sex	n	r	r^2	SEE kg	TE kg
SKIN	M	12	0.877	0.770	0.45	0.57
	F	13	0.373	0.139	0.41	0.39
	ALL	25	0.752	0.565	0.47	0.45
ADIPOSE	M	12	0.889	0.790	2.23	2.16
	F	13	0.762	0.580	5.26	5.29
	ALL	25	0.840	0.705	4.07	4.10
MUSCLE	M	12	0.951	0.905	2.41	2.23
	F	13	0.811	0.658	1.84	2.25
	ALL	25	0.941	0.885	2.30	2.25
BONE	M	12	0.824	0.679	0.83	1.01
	F	13	0.693	0.480	0.63	0.64
	ALL	25	0.792	0.628	0.86	0.84
RESIDUAL	M	12	0.639	0.409	1.09	1.11
	F	13	0.567	0.322	1.15	1.37
	ALL	25	0.717	0.513	1.13	1.25
BODY WEIGHT						
	M	12	0.983	0.965	2.43	2.27
	F	13	0.938	0.880	3.42	3.16
	ALL	25	0.963	0.927	3.01	3.79

Table 5.6 The correlation coefficient (r) and the standard error of estimate (SEE) and the total error (TE) in kg for the prediction of the tissue masses in 25 male and female cadavers from the Brussels cadaver study.

5.2.2 Prediction of skin mass in the cadaver sample

The weight of the skin is about 5% of the total body weight (Martin, 1984). As shown in Table 5.5, the error in predicting the skin weight in 25 cadavers is less than 2% (SD 14.3), which expressed in terms of the TE is less than 600 gm. This is probably the limits of accuracy for the prediction of skin mass from surface area, skin thickness and skin density, as each value used in the derivation of the mass represents a source of error, both biological and technical. As shown in Table 5.7, the use of sex specific cadaver derived constants, while maintaining the geometrical relationships of the original DuBois and Dubois (1916) formulae for the estimation of body surface area improved the prediction. These formulae may have relevance in studies where sex specific estimates of body surface area may be germane to the problem.

ACCURACY OF THE ANTHROPOMETRIC PREDICITON OF BODY SURFACE AREA BY THE METHOD OF DUBOIS AND DUBOIS (1916) AND A REVISED METHOD WITH CADAVER DERIVED SEX SPECIFIC CONSTANTS

constant	sex	n	OBSA m^2	(SD)	PBSA m^2	(SD)	CONSTANT ERROR %	(SD)
ORIGINAL								
71.84	M	9	1.61	(0.18)	1.69	(0.13)	5.9	(9.9)
71.84	F	11	1.66	(0.24)	1.63	(0.14)	-1.0	(9.0)
71.84	ALL	20	1.64	(0.21)	1.66	(0.13)	2.1	(9.8)
REVISED								
73.07	M	9	1.61	(0.18)	1.61	(0.12)	0.7	(9.4)
68.31	F	11	1.66	(0.24)	1.66	(0.14)	0.7	(9.2)
*	ALL	20	1.64	(0.21)	1.64	(0.13)	0.7	(9.0)

Table 5.7 Mean differences between obtained body surface area (OBSA), as derived from the Brussels Cadaver study and predicted body surface area (PBSA) using the original constants derived by DuBois and DuBois (1916) and revised cadaver derived constants for male and female cadavers.

* sex specific constant used to derive each PBSA separately.

5.2.3 Prediction of adipose tissue mass in the cadaver sample

Adiposity was underestimated in the female cadavers (-3.6%) and overestimated in the males by 5.8% (Table 5.5). The standard deviation was greater for the female group, which suggests a larger individual variation in the constant error for females than males. The total error (Table 5.6) also shows that adiposity is more accurately predicted in males (2.16 kg) than females (5.29 kg). This suggests a sex specific difference that the 5-way fractionation method is not accounting for.

The assumptions inherent in predicting adiposity from skinfolds will contribute to the total error (refer to section 2.7.1). Adipose tissue patterning is not fixed and varies between the sexes and individuals (Martin *et al*, 1985). The incorporation of regional sampling and geometrical scaling of skinfolds, should enhance the prediction of total adiposity with the 5-way fractionation method. However, individual differences still may not be sufficiently accounted for. Females deposit adiposity in the gluteal-femoral region, whereas males have more adiposity in the abdominal region (Bjorntorp, 1986). The gluteal-femoral site is not sampled and may account for the underestimation of adiposity in the female cadavers. The contribution of breast volume also is not sampled. This has been estimated as ranging from approximately 200-1500ml; assuming a density of 0.94g/ml for adipose tissue this is equivalent to about 190-1400g (Smith *et al.* 1986).

The overprediction of adiposity in males is not readily explainable. As the method is a departure model, it may be that male adiposity is over-represented by the predictor skinfold variables used in the method.

While the predictions of adiposity are not entirely satisfactory, when considered in comparison predictions obtained with percent body fat, the method achieves a similar level of predictability but is not a sample specific solution. High correlations of the order of 0.95 are frequently not replicated when the regression equations are cross-validated. Siri (1961) estimated the variance in using underwater weighing to estimate body density to be about 4%. The total error, due to biological and technical error, was estimated by Lohman (1981) as being 3.3% for the prediction of fat from skinfold caliper values. Flint (*et al*, 1977) assessed the validity of 11 prediction equations from skinfolds and using densitometry as the validation source. For estimating %body fat in women the 0.95 confidence interval ranged from +/- 5-8%. It can be concluded that the error in predicting adiposity in the cadaver sample are no worse than obtained with regression analysis. In addition, the solution is not population specific and does not require the acceptance of the assumption of constant density of the FM and the FFM.

5.2.4 Prediction of muscle mass in the cadaver sample

For the 25 cadavers, muscle mass was underpredicted by 1% (SD 11.8). There was minimal differences between the sexes (Table 5.5); the CE in males was -0.7% (SD 9.8) and for females was -1.2% (SD 13.8); this is equivalent to approximatelty 300g for males and 100g for females. Accuracy of prediction is supported by the SEE and the TE (Table 5.6). This indicates that a departure model, developed independently of the cadaver sample is able to predict muscle mass in males and females within 2.4 kg.

The regression model of Spenst (1986) was developed on male cadavers and applied to *in vivo* male subjects. Tested against the models of Matiegka (1921) and Heymsfield *et al.* (1982) the regression model was superior. A comparison of the constant error for the fractionation method and the regression equation (refer to section 2.7.3) is shown in Table 5.8. The overprediction in the female cadavers by 8%, for the regression model, indicates a sex specificity that would preclude application of the equation in females. Typically regression models validated in the same sample, show spurious correlations. The SEE for the regression model even with the inclusion of the 6 male cadavers used to develop the model (Table 5.9), does not demonstrate any advantage over the fractionation model. Hence, as the fractionation model is not a population specific model and predicts equally as well in males and females, it should be used in preference to the regression model.

ACCURACY OF ANTHROPOMETRIC PREDICITON OF TOTAL MUSCLE MASS BY THE 5-WAY FRACTIONATION METHOD AND A REGRESSION MODEL APPLIED TO 25 MALE AND FEMALE CADAVERS

		OBTAINED	FRACTIONATION			REGRESSION[1]		
		WEIGHT	MASS	CE[2]		MASS	CE	
	n	kg (SD)	kg (SD)	kg (SD)	% (%SD)	kg (SD)	kg (SD)	% (%SD)
MALES	12	25.1 (7.4)	24.8 (6.9)	-0.3 (2.3)	-0.7 (9.8)	24.8 (8..0)	-0.3 (2.1)	-1.8 (9.9)
FEMALES	13	17.8 (3.0)	17.6 (4.0)	-0.1 (2.3)	-1.2 (13.8)	19.1 (3.2)	1.3 (2.2)	8.1 (12.4
ALL	25	21.3 (6.6)	21.1 (6.6)	-0.2 (2.3)	-0.9 (11.8)	21.8 (6.6)	0.5 (2.2)	3.4 (12.1)

Table 5.8 Differences between obtained and predicted muscle mass in predicting muscle by the 5-way fractionation method and a regression model (Spenst, 1986) applied to 25 male and female human cadavers.

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1 The regression equation of Spenst was developed on 6 male cadavers and tested applied to the male cadaver sample and in vivo male subjects. There were no recommendations for the use of the model in females. However, application of the model to the females cadavers showed a tendency toward overestimation.

2 CE is the mean difference between the predicted mass and the obtained weight (P-O) in kg or as a percent where %CE is ((P-O)/O)*100

COMPARISON OF THE 5-WAY FRACTIONATION METHOD AND A REGRESSION MODEL FOR THE PREDICTION OF TOTAL MUSCLE MASS IN A CADAVER DATA ASSEMBLY.

		REGRESSION[1]			FRACTIONATION		
	n	r	r^2	SEE kg	r	r^2	SEE kg
M	12	0.969	0.940	2.05	0.951	0.905	2.22
F	13	0.747	0.558	2.25	0.811	0.658	2.43
ALL	25	0.943	0.889	2.23	0.941	0.885	2.27

Table 5.9 The correlation (r). and the standard error of estimated (SEE) in kg, for the prediction of total muscle mass in 25 cadavers by the 5-way fractionation method developed independent to the sample and the regression model of Spenst (1986). which was developed and validated in the male cadaver sample.

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[1] Spenst (1986)

5.2.5 Prediction of bone mass in the cadaver sample

The prediction of bone mass was overestimated by 3.7% (SD 8.2) in the female cadavers and underestimated in males by 6.7% (SD 8.7). The total error for both males and females was within 1 kg. The direction of the constant error suggests a sex difference due to bone density differences may account for a large portion of the error. Demineralization of the bone mass occurs in both sexes, but is greater in females (Mazess, 1982). However, as the bone mass predicted from surface anthropometry must assume indirectly a constancy of density, it is apparent that density changes cannot be detected. The net loss in skeletal mass with aging has been estimated at 137g, which represents a loss of about 2% per decade (Martin, 1984). The total error for the bone mass in females was over predicted 640g, which would suggest that with an adjustment for the bone density the prediction error may be reduced.

5.2.6 Prediction of residual mass in the cadaver sample

Residual mass was predicted within 1% (% SD 15.4) for the 25 cadavers, with females being underpredicted (- 1.6%) and males slightly overpredicted by 0.6%. The

rationale used of scaling the residual mass to sitting height and the selected predictor variables appear to be adequate.

5.3 COMPARISON OF THE 5-WAY FRACTIONATION METHOD WITH THE GEOMETRIC MODEL (DRINKWATER, 1984)

The criterion test of adequacy for the 5-way fractionation method was to compare its performance to the geometric model. The differences between predicted and obtained tissue weights for the fractionation method and the geometric method (Drinkwater, 1984), applied to the cadaver sample are shown in Table 5.10. The geometric model was applied to 20 available cadavers, for which weights and volumes were measured on all tissues (refer to section 2.8.5). Of the 20 cadavers, 10 were randomly selected for determining the volume coefficients; these were derived from the calculated tissue volumes and the true tissue volumes. The volume coefficients were cross-validated on the remaining 10 cadavers and were shown to overestimate the tissue by 1.7-7.5%.. The volume coefficients were then decreased. As the geometric model was developed on part of the cadaver sample it may have an advantage over the fractionation model.

For the prediction of the skin mass the geometric model is more accurate; both the percent constant error and percent SD are less. However, loss of dermal volume is known to occur with aging (Gilchrest, 1982) so that in a younger population the overprediction by the fractionation model is likely to be reduced.

The smaller SD for the prediction of adipose tissue by the geometric model indicates smaller individual errors of prediction. For the prediction of muscle mass there was little difference in the constant error between the two models, with SD being less in

the fractionation model. Similarly, the estimation of the bone mass was similar for both approaches. In the prediction of the residual mass the fractionation method is the more accurate predictor. Based on these results the differences in the two models are minimal and no distinct advantage is demonstrated by either approach.

Application of both methods to *in vivo* samples, are shown in Table 5.11. Differences in the sample size indicate missing data as different anthropometric variables are used in the two models. The geometric model is clearly superior in the body builder sample; the % constant error is -0.4%, whereas by the fractionation method the CE was 8%. The fractionation approach however, performs better in the olympic athletes (MOGAP).

ACCURACY OF THE ANTHROPOMETRIC PREDICTION OF THE TISSUE MASSES BY THE 5-WAY FRACTIONATION METHOD AND THE GEOMETRIC MODEL APPPLIED TO A CADAVER DATA ASSEMBLY

	FRACTIONATION		GEOMETRIC	
tissue	n	%CE[a] (%SD)	n[b]	%CE (%SD)
SKIN	25	1.9 (14.3)	20	-0.8 (11.7)
ADIPOSE	25	0.9 (18.3)	20	-0.3 (14.6)
MUSCLE	25	-1.0 (11.8)	20	1.1 (13.4)
BONE	25	-1.3 (9.8)	20	-1.1 (10.9)
RESIDUAL	25	-0.5 (15.4)	20	5.9 (24.1)
WEIGHT	25	-1.8 (3.0)	16	0.0 (3.9)

Table 5.10 Percentage mean differences (%CE) between predicted and obtained tissue weights for the 5-way fractionation method and the geometric model (Drinkwater, 1984) for all male and female cadavers, Brussels cadaver study.

[a] %CE is the mean constant error expressed as a percentage (((P-O)/O)kg*100%)

[b] For the geometric model derivation and validation was completed on 20 cadavers for which were complete in all variables.. Using the same 20 cadavers to predict the fractional masses by the 5-way fractionation method the %CE for each mass were as follows: skin 2.4% (14.3), adipose 2.9% (19.5), muscle -0.9% (12.4), bone -2.4% (10.5) and residual -3.8% (13.5).

ACCURACY IN THE PREDICTION OF BODY WEIGHT OF MEAN VALUES FOR THE FRACTIONATION MODEL AND GEOMETRIC MODEL APPLIED TO IN *IN VIVO* AND CADAVER ANTHROPOMETRIC DATA ASSEMBLIES

MODEL		FRACTIONATION MODEL			GEOMETRIC		
sample	sex	n	% CE	SD	n	% CE	SD
CADAVER							
	M	12	-0.4	(3.5)	8	-0.9	(3.4)
	F	13	-3.0	(5.0)	8	0.8	(4.3)
	ALL	25	-1.8	(4.5)	16	-0.0	(3.9)
CANAD							
	M	95	3.5	(4.2)	151	-2.8	(4.6)
	F	120	3.0	(4.6)	94	-0.9	(4.0)
	ALL	215	3.2	(4.4)	245	-2.1	(3.4)
MOGAP							
	M	308	0.3	(3.6)	308	-2.0	(3.4)
	F	148	-0.9	(4.1)	148	-2.4	(3.5)
	ALL	456	-0.1	(3.8)	256	-2.2	(3.4)
BUILD							
	M	66	8.1	(3.0)	66	-0.4	(3.2)
COGRO							
	M	447	1.6	(6.3)	449	-0.7	(4.9)
	F	425	1.6	(5.5)	430	-1.7	(4.2)
	ALL	872	1.6	(5.9)	879	-1.2	(4.6)

Table 5.11 Percent differences between predicted and obtained body weights as determined from the application of the 5-way fractionation model and the geometric model (Drinkwater, 1984) to: cadavers, non-athletic adults 18-35 yrs (CANAD), competitive athletes (MOGAP), competitive body builders (BUILD), children aged 6-18 yrs (COGRO).

%CE is the mean constant error expressed as a percent: (%CE= ((P-O)/O *100)

Based on these results it is concluded that the 5-way fractionation method compares favorably with the previously validated geometric model and furthermore, in the living, the fractionation method is able to account for the variance in human physique in both sexes and across the ages. In extremely dysplasic samples, such as body builders, the geometric model appears to be the method of choice. The advantage of the fractionation model over the geometric model is that it was derived independently of the cadaver data and therefore is not a sample specific solution.

VI. CHAPTER 6: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY

A new anthropometric human body composition method was designed to estimate the fractional masses of skin, adipose tissue, muscle, bone and residual tissue masses, in 1669 males and females aged from 6 to 77 years. The method made use of geometrically adjusted departures from a single unisex reference human to derive each tissue mass. With the exception of the skin mass, which was derived separately from predicted body surface area and used cadaver derived constants for skin density and thickness, the remaining tissues were derived independently of the cadaver sample and without using body weight as a predictor variable. The method had two constraints

(1) the sum of the predicted fractional masses was to approximate the individual obtained body weight in 11 *in vivo* samples, representing a wide variety of human physique.

This constraint was met as indicated by the ability of the method to predict total body weight in all living subjects within 1.6%, with a correlation coefficient of 0.987 and a SEE of 3.00kg. In 9 of the 11 samples the correlation coefficients ranged from 0.985 for girls aged 6-17 yrs, to 0.931 for female university students. Male and female lightweight rowers showed the lowest correlations (0.608 and 0.509, respectively), indicative of the

minimum variability in their body weight. The SEE for all lightweight rowers was 1.63kg; the lowest for all samples. The sum of the predicted fractional masses accounted for total body weight across all samples within 4%, with the exception of the body builder sample. An overestimate of 8% in this group was attributed to their extreme physique and possible dehydration at the time of measuring.

(2) the individual tissue masses and the sum was to be consistent with anatomical evidence from the dissection of 12 male and 13 female human cadavers.

The sum of the tissue masses underestimated total body weight in the male cadavers by -0.4% and in the female cadavers by -3.0%. With the exception of the predicted bone mass in males, the differences between obtained and predicted tissue masses were not significant. Furthermore, the 5-way fractionation method, developed externally to the cadaver database, was shown to be as good as the regression model of Spenst (1986) applied to males, and the geometric model (Drinkwater, 1984) applied to male and female cadavers. Therefore, the predictive advantage of the proposed method in this thesis was demonstrated. The 5-way fractionation method, being independent of age and sex, is recommended for ascribing group characteristics using standard anthropometry. In the absence of other methods of a similar kind, it is considered appropriate as a preliminary estimate of the tissue masses.

6.2 CONCLUSIONS

The development of the 5-way fractionation method has evolved from

1. original concepts of Matiegka (1921)
2. was extended further by Drinkwater (1984)
3. merged with the PHANTOM stratagem originally proposed by Ross and Wilson (1974)

While appearing to be a sample independent universal system the limits have not been defined. The advantages of the 5-way fractionation method over other systems are:

1. Uses standard anthropometry, in accordance with the International Working Group on Kinanthropometry and thus,
   (a) augments other cross-sectional and longitudinal database systems
   (b) provides supplementary analysis, which is inexpensive and non-invasive
   (c) has professional application in combination with existing systems.

2. As the design is similar to other models that utilize geometrical scaling, it can be used with supplementary and complementary systems; for example
   (a) the scaling factor related to the third component (ectomorphy) of somatotyping and is the same as the second component (endomorphy)

(b) z-values used in the derivation of the fractional masses are identical to those used in the O-scale system. Errors in prediction of total body weight, can be compared for structural differences relative to the individual's own age and sex norm, using the O-scale system

(c) as it is related to the PHANTOM stratagem and therefore, z-values can be compared with any other z-values derived from different databases.

3. The method demonstrated it is equal to both the regression model of Spenst (1986) and the geometric model of Drinkwater (1984). However, if one considers that the fractionation approach is derived independently of the cadaver sample and does not have the advantage of spuriousness inherent in both models, the 5-way fractionation method is superior.

4. Obtained body weight is used as partial validation that the sum of the fractional tissue masses is accurately predicted.

The method as presented, is a workable model which has application for individual appraisal, in monitoring changing status. For group assessment the method has demonstrated that it is sex and age independent.

> Cyclic fluctuations along the acceptance-rejection continuum are not unusual in the history of scientific methods. In the first, positive, creative stage the investigators, especially those who directly participated in the development of a new approach, are apt to be enthusiastic. They are impressed by how good the first approximations are. In the second, the critical, stage, the fact that these were only the first approximations is likely to be emphasized. The complexities of methodology, glossed over at first, are likely to be found overwhelming. The quantitative assumptions are questioned and the size of the standard errors stressed. It becomes clear, in time, that definitions must be sharpened, ambiguities of terminology reduced or eliminated, and quantitative assumptions replaced by factual data based on well-defined samples (Brozek, 1963).

The 5-way fractionation method, as proposed in this thesis, is considered a part of this process and not the final solution.

6.3 RECOMMENDATIONS

1. The 5-way fractionation method should be used concomitantly with other methods based on assumptions and ascribed constants and in particular, should be applied to the longitudinal monitoring of growth and development in children.

2. The precision and accuracy of the method should be explored with further information; for example

(a) additional cadaver evidence across a wider age distribution and in particular, comprehensive cadaver dissections on children is needed

(b) with new instrumentation, such as medical imaging, adjustments for individual variability in bone density and internal adiposity. can be built into the method

(c) while delineated from this thesis, algorithms for uncompressed skinfolds as determined by ultrasound (Anderson, 1986), could may reduce the compressibility error with skinfolds and could be used as an alternate technique

(d) alternate anthropometric items may be substituted to determine the effectiveness.

3. The model is recommended for use concurrently with studies of metabolic events, where scaling to the relevant tissue masses would size dissociate; for example, maximum oxygen uptake per kg of muscle mass to the two-thirds, as geometrically expected (Bailey *et al.*, 1978).

4. Applicability for monitoring change in status, should be tested by professional and clinical experience.

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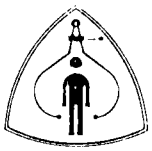

BASIC ANTHROPOMETRIC PROFORMA

Kinanthropometric Research Associates
Department of Kinesiology
Simon Fraser University

A	01. Subject _____ (Last Name) _____ (Given Name)							1	
	02. Card Number _____							6	1
	03. Identity 7 Sex f=2 m=1				8 checker number			7	
B	04. Date of observations	Year		mo.		day		9	
	05. Date of birth	Year		mo.		day		14	
	06. Measurement sequence no.							19	
	07. Body mass							20	
	08. Stature (stretched)							24	
C	09. Triceps sf _____							28	
	10. Subscapular sf _____							31	
	11. Biceps sf _____							34	
	12. Iliac crest sf _____							37	
	13. Supraspinale sf _____							40	
	14. Abdominal sf _____							43	
	15. Front thigh sf _____							46	
	16. Medial calf sf							49	
D	17. Acromial height _____							52	
	18. Radial height _____							56	
	19. Stylion height _____							60	
	20. Dactylion height _____							64	
	21. Spinale height _____							68	
	22. Trochanterion height _____							72	
	23. Tibiale (laterale) height							76	
	24. Subject _____							1	
	25. Card Number							6	2
E	26. Arm girth relaxed _____							7	
	27. Arm girth flexed and tensed _____							10	
	28. Forearm girth (max. relaxed) _____							13	
	29. Wrist girth (distal styloid) _____							16	
	30. Chest girth (mesosternale) _____							19	
	31. Waist girth (min.) _____							23	
	32. Gluteal girth (max.) _____							27	
	33. Thigh girth (1 cm dist. glut.fine)							31	
	34. Calf girth (max.) _____							34	
	35. Ankle girth							37	
F	36. Biacromial breadth _____							40	
	37. Bicristal breadth _____							43	
	38. Transverse chest breadth _____							46	
	39. Foot length (ak–pte) _____							49	
	40. Humerus width _____							52	
	41. Femur width							56	
G	42. Sitting height _____							60	
	43. Anterior posterior chest depth _____							64	
	44. Head girth _____							67	
	45. Neck girth _____							70	
	_____								
	_____								
	_____								

APPENDIX B RAW DATA FROM THE BRUSSELS CADAVER STUDY (DRINKWATER, 1984; MARTIN, 1984)

ID	GROUP	SEX	AGE	SUPINE	HT[a]	TRLT	SITHT[b]	WTD	WTR
3	EMBAL	MALE	73	157.1	156.2	73.10[c]	86.16	52.8	00.0
5	EMBAL	MALE	78	163.8	162.8	78.60	89.36	70.4	0.00
6	EMBAL	MALE	78	168.0	167.0	82.80	91.81	71.5	69.9
9	EMBAL	MALE	70	160.1	159.2	77.50	88.72	58.5	52.4
10	EMBAL	MALE	83	163.5	167.5	83.85	92.42	51.7	46.4
13	EMBAL	MALE	72	166.8	165.8	79.85	90.09	65.1	60.7
17	UNEMB	MALE	65	167.1	166.1	79.25	89.74	54.8	54.8
20	UNEMB	MALE	59	174.2	173.2	80.75	90.62	76.8	76.8
23	UNEMB	MALE	81	177.9	176.9	85.05	93.12	61.0	61.0
25	UNEMB	MALE	73	173.0	172.0	88.70	95.24	85.1	85.1
26	UNEMB	MALE	73	164.6	163.6	83.10	91.98	57.7	57.7
27	UNEMB	MALE	55	187.6	186.5	91.90	97.11	88.9	88.9
4	EMBAL	FEMALE	83	149.2	148.3	72.10	80.74	61.6	0.00
7	EMBAL	FEMALE	94	152.4	151.5	72.20	80.82	49.1	44.3
8	EMBAL	FEMALE	79	158.0	157.1	76.60	84.49	48.3	45.2
11	EMBAL	FEMALE	84	158.7	157.8	82.25	89.20	75.4	68.8
12	EMBAL	FEMALE	69	169.6	168.6	86.85	93.04	62.9	61.4
14	EMBAL	FEMALE	70	161.2	160.2	73.60	81.99	63.4	60.4
15	UMEMB	FEMALE	79	160.7	159.7	79.75	87.12	58.9	58.9
18	UNEMB	FEMALE	83	173.3	172.3	80.70	87.91	74.2	74.2
19	UNEMB	FEMALE	82	162.6	161.7	81.50	88.58	48.2	48.2
21	UNEMB	FEMALE	77	152.2	151.3	73.25	81.70	71.6	71.6
22	UNEMB	FEMALE	68	154.5	153.6	69.80	78.82	69.0	69.0
24	UNEMB	FEMALE	86	157.4	156.5	75.60	83.66	61.2	61.2
28	UNEMB	FEMALE	82	164.4	163.5	91.60	97.00	68.8	68.8

[a] estimated stature = supine length * 0.9934714 + 0.9529669 +/- 0.815 cm (Drinkwater, 1984)

[b] estimated sitting height for MALES: SITHT=((0.582295*TRLT)+43.595332)
for FEMALES: SITHT=((0.833756*TRLT)+20.626160)

[c] for subject 3 estimated trochanterion length TRLT = =((0.650493*BACKLT)+(0.202622*SUPINE)+8.030630)

ID	ADIPOSE TISSUE THICKNESS (mm)					
	triceps	subscap -ular	suprasp -inale	abdom -inal	thigh	medial calf
3	16.25	14.25	19.85	17.00[d]	20.05	22.40
5	15.30	16.95	12.35	18.05	15.75	13.00
6	18.70	10.95	7.15	14.55	14.45	7.10
9	15.85	14.00	6.30	16.30	12.80	5.55
10	12.10	8.20	4.05	9.30	9.05	7.25
13	26.00	18.05	8.20	11.50	11.60	5.85
17	15.00	9.10	5.05	12.30	6.15	4.65
20	18.10	18.25	12.15	19.45	20.45	17.45
23	10.80	8.10	4.95	13.25	10.15	8.20
25	23.30	21.85	14.45	20.40	22.35	10.15
26	16.60	17.90	10.70	28.70	24.90	16.60
27	11.05	11.50	6.85	12.85	18.55	10.00
4	47.50	36.40	23.00	25.80	30.35	17.55
7	13.05	7.70	4.60	10.80	15.05	16.00
8	19.80	10.65	8.45	19.10	13.30	18.90[e]
11	46.35	21.35	21.65	20.40	35.60	31.50
12	26.65	12.90	6.80	16.85	19.80	18.88
14	26.60	9.60	10.85	20.50	17.75	16.10
15	28.15	12.55	26.25	31.65	21.65	22.35
18	13.20	15.65	23.90	22.60	41.15	35.80
19	23.40	9.85	16.00	35.15	23.40	17.25[e]
21	22.35	21.70	12.95	25.35	43.75	16.30
22	28.35	17.80	12.75	27.25	29.90	23.60
24	25.80	12.95	23.30	22.80	28.80	29.50
28	23.25	16.55	12.65	20.85	28.80	18.75

[d] denotes estimated abdominal (ABSF) skinfold for male cadavers determined by ABSF = ((direct supraspinale*0.720331) + (supraspinale*-.024010) + (direct ABSF*.116875) + 4.798250)

[e] denotes estimated medial calf skinfold (MCSF) for females determined by MCSF = ((direct thigh skinfold* -.0269531) + (mid-thigh skinfold*.11745) (direct MCSF*.903728) + (rear thigh skinfold*.050338) + (direct mid-thigh skinfold*.424536) + (direct thigh skinfold*.55351) (thigh skinfold * -.132972) -12.727286) where the direct skinfold is as measured by cadaver dissection.

	girths						breadths			
ID	arm	forearm	chest	thigh	calf	head	biacr	biili.	femur	humerus
3	24.70	22.00	86.50	48.05	27.60	55.70	31.20	25.90	9.71	6.13
5	30.10	25.80	95.15	48.75	36.15	53.80	37.15	30.52[e]	9.57	6.51
6	29.65	26.80	99.90	46.75	31.90	59.05	36.30	30.84[e]	10.46	8.08
9	26.35	24.50	96.30	43.10	26.00	54.55	37.60	30.39[e]	9.35	7.65
10	23.40	22.25	89.95	34.65	20.52	55.25	36.90	30.48[e]	9.80	7.05
13	29.85	28.55	93.50	46.75	32.45	56.95	35.35	30.30	9.50	7.63
17	25.50	22.85	89.25	44.70	28.30	56.26	36.70	30.10	9.78	7.21
20	28.05	26.40	97.85	52.50	39.25	55.45	37.75	30.95	10.70	7.27
23	24.65	21.75	88.80	44.80	30.80	55.90	37.25	32.20	9.55	6.73
25	33.00	28.25	104.45	54.90	35.40	59.60	39.30	31.45	10.23	7.61
26	26.60	22.00	88.30	46.40	27.25	54.70	36.40	29.70	9.49	6.08
27	31.40	29.10	97.00	56.55	36.45	57.85	40.30	32.25	11.19	8.03
4	30.15	28.85	92.70	47.15	28.30	55.85	35.40	32.44[e]	9.13	6.10
7	23.25	21.75	77.40	47.35	29.15	52.20	33.30	29.90[e]	9.03	6.53
8	24.15	22.15	73.10	44.20	31.40	53.60	38.55	30.24[e]	9.07	6.23
11	31.35	26.65	94.40	56.15	33.70	55.75	34.45	31.82[e]	9.82	6.73
12	25.55	23.55	84.40	47.55	32.75	56.75	36.45	34.35	9.77	7.44
14	28.00	24.75	84.10	52.00	29.15	54.72	34.05	31.25	9.27	6.81
15	28.40	23.10	78.85	50.75	30.10	56.55	34.75	27.85	9.56	6.90
18	29.85	22.40	84.50	52.30	22.30	54.80	36.10	31.80	10.11	6.82
19	23.60	20.25	73.80	44.35	26.25	52.90	35.25	31.05	9.55	6.76
21	32.20	27.60	87.00	56.15	32.20	56.80	37.85	30.15	10.07	7.00
22	33.00	24.25	86.35	53.95	34.75	53.40	33.00	29.80	10.47	6.88
24	26.70	23.15	82.94[g]	50.00	29.00	54.55	36.65	30.95	9.94	6.50
28	28.60	24.65	81.55	52.80	32.40	53.50	35.00	31.35	9.76	6.85

[f] biiliocristal breadth estimated for these cadavers from
males: BIIL = ((0.209572*biiliospinale) + (0.119744*bitrochanterion) + 21.46490)
females BIIL= ((0.305217*biiliospinale) + (0.018528*bitrochanterion) + 22.557157)

[g] chest girth estimated for subject 24 by
CHG = ((0.069848*chest girth axillary base) + (0.018575*chest girth xiphoid) + 0.766312)