HUMAN BODY COMPOSITION: MODELS, METHODS, APPLICATIONS

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INTRODUCTION

Body composition and body size depend on genetic determinants, the activity of the organism, and the effects of the environment, in the broad sense, including the exposure to infection and parasites and, importantly, the diet.

The coin, then, has two sides: 1. diet *is* a factor affecting body composition, and 2. diet *is not* the sole factor.

If we regard body composition as the basic facet of man's "nutritional status" (nutriture), we do so in the sense of Brock's definition of human nutrition, which points to those aspects of the structure and function of the body which are "particularly dependent on proper feeding". (16)

Thus, in principle, all research on body composition, in and out of strictly dietary contexts, is of interest to students of human nutrition. This includes *factors* determining body composition (such as diet) as well as appraisal of the biomedical *significance* of differences in body composition, assessed in reference to fitness (including resistance to stress, such as cooling), (42) and to health prognosis. (54, 105, 144)

The incorporation of chapters on body composition in textbooks of human nutrition may be viewed as a formal acknowledgement of the relevance of research on body composition to human nutrition. More than that: Both in the leading British textbook, *Human Nutrition and Dietetics*, by *Davidson* and *Passmore*, (49) and in the new edition of *Modern Nutrition in Health and Disease*, edited by *Wohl* and Goodhart, (94) the treatment of body composition is reserved for the first chapter, thus attesting to its fundamental significance.

Historically, the weight of the body, considered in reference to the skeletal frame, its length and preferably also its width, (20) has long been regarded as an important indicator of man's nutritional status. The use of body measurements in this context has come to be referred to as "nutritional anthropometry".

Nutritional anthropometry acquired a "new look" when anthropologists added skinfold thicknesses to measurement of lengths and circumferences. This pointed a way from the surface to the "inner man".

It was in connection with his endeavors to provide a more sophisticated, more useful somatometric criteria of nutritional status that the Czech anthropologists, *Matiegka*, some 45 years ago, (109) developed a system for breaking down the gross body weight into its major components. His equations provided for the estimation of body composition in terms of the weight of the skin and subcutaneous adipose tissue, of muscles, and of the skeleton. The estimation equation were based on the measurements of selected body dimensions and skinfold thicknesses.

In the last 25 years the area of the study of body composition blossomed out remarkably. The methodology that proved fruitful for laboratory and clinical research was based on determinations of body density and of total body water and its compartments, by dilutional techniques. The latter development, enriched by the determinations of electrolytes, especialy the total exchangeable potassium, culminated in the multi-parameter approach developed by F. D. *Moore* and his coworkers. (106) The students of human growth contributed the radiographic approach to the analysis of body composition in which the limb width can be separated, quantitatively, into the osseous, muscular, and adipose components.

The applications are as varied as the techniques themselves. They include, importantly, applications relevant to the science of human nutrition: 1. Evaluation of *nutritional status* of individuals (in the "normal" range of leanness-fatness and at its extremes, with special reference to obesity) and of populations. 2. Quantitative analysis of *changes* in body composition, be they associated with weight gains or weight losses or may they represent — as sometimes happens — a change in the *proportion* of different body tissues, without alteration of gross body weight. The changes may be induced by alterations of the diet, especially by the calorie balance (as in weight reduction) or by other factors, including disease.

Implications of compositional ("somatolytic") techniques to human nutrition are documented in the journal literature, in the content of the proceedings of research conferences (31, 32, 33) and in specialized monographs. (116)

The literature on the subject is large. Thus even in the relatively narrow field of research on chemical composition of the body, a recent review cites some 800 references. (155) Stitt's bibliography on skinfolds registers 237 titles. (146)

Any attempt in the present context at completeness of coverage would not only be inappropriate but hopeless as well. Consequently, we shall emphasize fundamental concepts and focus on recent publications.

MODELS AND ESTIMATION EQUATIONS

There are different ways of separating, conceptually and operationally, the human body into its components. We are concerned here primarily with the whole body and its componental analysis by indirect methods ("somatolysis"). But we shall consider, briefly, also a body-composition model of the anatomist.

Anatomists' Handwork

In the context of studies on developmental anatomy, Scammon and his coworkers subdivided the body into five anatomical compartments: Skin and fat, viscera, nervous tissues, muscles and skeleton. (136) Wilmer's paper provides information, reproduced by Scammon, on body composition of the human fetus at six months, of the newborn and of the "adult" in terms of the relative amounts of these five categories. (156)

In further analysis, Scammon subdivided the compartment "skin and fat" into two parts. This was a correct step, justified by the profound differences in their age trends. According to Scammon, the weight of the skin constitutes about 4 % of the body weight at six lunar months and at birth, and about 6 % of the body weight in the average adult. By contrast, the subcutaneous adipose tissue is present only as a trace at five lunar months but represents some 12 % of the body weight at birth. The relative amounts of adipose tissue at maturity were given as 10 % in men and over 20 % in women.

The separation of the complex "skin and subcutaneous tissue" into its two, anatomically separable parts, illustrates the application, on the anatomical level, of the important "principle of increasing homogeneity". The principle is relevant to the progress in the analysis of body composition in the framework of indirect methods. We may also speak, with a somewhat different emphasis, of a "principle of successive approximations". (30)

Somatometric Models

Matiegka's early model of body composition was three-componental and, if we consider the inescapable "remainder" (R), four-componental. (109) The folowing three components were estimated on the basis of body measurements: the weight of the skeleton ("ossa", 0), skin ("derma", with the subcutaneous adipose tissue, D), and skeletal muscles (M). Thus the body weight (W) was broken down as follows:

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

This model, and Matiegka's approach in general, is intersting primarily from a historical point of view, except for research on the estimation of the skeletal mass. (160)

It should be noted that the weights of bone, of skin and subcutaneous adipose tissue, and of muscle were estimated by Matiegka independently of one another, i.e. they represented separate and separable components of body weight. In later work, emphasis was shifted to the estimation of total body fat, via predictions of body density or of "lean body mass", thus reducing the model to two components. Two-componental is also Garn's model based on roentgenographic measurements of subcutaneous fat. (70)

From the "reference body" to in vivo analysis

From the point of view of the biochemist concerned with de-composition of the body into its components, the human body may be reviewed as a four-component system:

Body Weight = Fat + Water + Protein + Mineral

This is a "radical" model, operating with chemically defined, fundamental components. It has the advantage of simplicity and finality. For certain purposes it may be profitable to separate the total mineral into the osseous (M_O) and the non-osseous or residual (M_R) mineral. This yields, then, a 5-componental model.

In these terms we characterized the composition of a "reference body", using the best available though meager data, obtained by pooling information on 3 male cadavers. (34) Table 1 gives weights

TABLE 1

Weights, densities and volumes of the components of 1 kg of the "reference body"[34]

Symbol	Component	Weight (g)	Density at 36 °C	Volume (ml)
A	Water	624.3	0.99371	628.2
P	Protein	164.4	1.34	122,7
F	Fat	153.1	0.9007	170.0
M_O	Bone (osseous) mineral	47,7	2.982	16.0
M_R	Residual (non-osseous) mineral	10.5	3.317	3.2
Total		1000.0	(1.064)	940.1

and volumes of the components of the total reference body. Table 2 indicates the composition of four compartments (fat-free mass; fat-free, bone-mineral-free mass;, a compartment labeled "cell residue" and defined as the sum of intra-cellular water, protein and non-osseous mineral; and fat-free "cell residue" solids). The water content of the "cell residue" was obtained as intracellular water (total water less the extracellular water, taken as 160.0 g/kg of body weight).

The non-availability of practical methods, in vivo, for the direct estimation of protein (P) and total mineral (M), necessitates their combination into a single compartment which may be designated as S, for total body solids: $S = P + M$.

TABLE 2

Relative composition (%) and the computed density of the reference body and four of its compartments[34]

Compartment / Characteristic	Reference body	Fatfree mass	Fatfree, bone-mineral-free mass	"Cell residue"	Fatfree "cell residue" solids
Water	62.4	73.8	78.1	72.7	
Protein	16.4	19.4	20.6	25.7	94.0
Fat	15.3				
Osseous mineral	4.8	5.6			
Non-osseous mineral	1.1	1.2	1.3	1.6	6.0
Per cent of total body	100.0	84.7	79.9	63.9	17.5
Density	1.064	1.100	1.060	1.078	1.389

Our personal preference is to view S as a "remainder", since it contains, in reality, all the components that are not fat (defined operationally as ether extract) and water. (30) It includes the body's carbohydrates, negligible as their amount may be for practical purposes. Passmore estimates the carbohydrate stores in the adult human body at only 500 grams. (130)

By combining mineral and protein into a single, larger and more heterogeneous compartment, we reduce the body composition model to three components, with the total body weight divided into body fat (F), body water (A), and the residue (S) which is largely mineral and protein:

$$W = F + A + S$$

On the basis of the data presented in Table 2, S may be defined as the sum of protein, osseous mineral and non-osseous mineral, yielding, per kilogram of the reference body, a weight of 222.6 g, a volume of 141.9 ml, and a density of 1.569 g/ml. This is very close to Siri's estimate of 1.565. (142) However, this closeness should not be too surprising since both estimates are derived from the same general body of data.

With information on the densities of the components at hand, we can proceed in a straightforward fashion to develop a formula, based on the "reference body", for the estimation of total body fat. Let us recall that density is a ratio of weight to volume ($D = W/V$; consequently $V = W/D$). For the body as a whole,

$$D = \frac{F + A + S}{V_F + V_A + V_S}$$

Expressing all values as fractions of body weight ($f + a + s = 1$), replacing the volumes by ratios of weight and density, and expressing the *s* component as a difference ($s = 1 - f - a$) we obtain,

$$D = \frac{1}{\frac{f}{d_F} + \frac{a}{d_A} + \frac{(1 - f - a)}{d_S}}$$

This yields total body fat, expressed as a fraction of body weight and as a function of body density (D) and total body water (*a*),

$$f = \frac{2.115}{D} - 0.780a - 1.348$$

The terms in the equation differ negligibly from the equation proposed by Siri (142, Equation 21, p. 236).

A three-componental model in which

Body Weight = Fat + Water + Fatfree dry solids is also the basis of the approach developed by Talso et al. (147). The fatfree solids are estimated from the potassium content of the body, obtained by K^{42} dilution. By adding to this compartment the total body water we obtain the fat-free body weight. Fat is obtained by difference (total body weight less fatfree weight).

When it is technically feasible to determine only total body water or only body density we are reduced to a two-componental model, with body weight separated into body fat and the fatfree fraction:

$$W = F + Ff$$

The density of this system,

$$D = \frac{W}{V_F + V_{Ff}}$$

may be expressed as

$$D = \frac{1}{\frac{f}{d_F} + \frac{(1 - f)}{d_{Ff}}}$$

Using the densities of the components given in Table 2 ($d_F = 0.9007$, $d_{Ff} = 1.100$), we obtain f, as a fraction of body weight, as

$$f = \frac{4.971}{D} - 4.519$$

An alternative approach is based on the measurement of total body water alone. As indicated in Table 2, water (A) constitutes 73.8 per cent of the weight of the fat-free body ($A/Ff = 0.738$). Accepting, at least provisionally, this ratio as a valid biological constant, we can express body weight ($W = F + Ff$; $1 = f + ff$) as

$$1 = f + \frac{a}{0.738}$$

yielding f as $f = 1 - 1.355a$

where *a* is the total body expressed as a fraction of body weight and f is total body fat.

The densitometric and the hydrometric estimates of total body fat are based on the same set of interrelations and quantitative assumptions. It can hardly be overemphasized that these estimates are only approximations, as are the constants which are built into the estimation equations. The consequences of the imprecision with which we can carry out measurements of density and body water ("errors of measurement") and the effects of individual variation of the biological "constants" were considered, critically, by Siri. (142)

In spite of its limitations, the simple, two-componental model has provided the basis for much of the work on body compositions. It represented the first but important step in the endeavor to arrive at components of the human body which increase, progressively, in homogeneity and functional specificity.

Models in Whole-Body Radiometry

The two-component model (Weight = Fat + Fatfree mass) is basic to other approaches than those of densitometry and hydrometry. Thus Forbes, Gallup and Hursh (65) proposed a formula for calculating the fat-free component of gross body weight, based on the assumption that potassium represents a constant fraction of fatfree body weight (Ff):

$$\frac{\text{total K}}{\text{Fatfree weight}} = c$$

This is a general formula, analogous to the formula which relates total body water to fatfree weight.

In the specific formula of Forbes et al., (65) the value "c" is taken as 68.1 and the potassium is expressed in milliequivalents:

$$\text{Ff, kg} = \frac{\text{measured total K (mEq)}}{68.1}$$

In their system, as in the hydrometric approach, total body fat is obtained by difference:

$$\text{F} = \text{Body Weight} - \text{Fatfree Body Weight}$$

The amount of total body potassium was measured on the basis of radioactivity due to the presence of a naturally occurring isotope of potassium (K^{40}), using a whole-body counter.

The radiometric approach of Forbes et al. shares the limitations inherent in all systems for the analysis of body composition which operate with the concept of a fatfree mass that is constant in its composition — an assumption that has only approximative validity.

In regard to potassium concentration, the fatfree mass is far from being homogenous. Specifically, both the fatfree residue of the adipose tissue (56 mEq/kg) and skin, tendons, and bone (21 mEq/kg) have a lower potassium content that muscles and viscera (in the range from 95 to 100 mEq/kg, in the rat). Thus both in a heavy-boned and in an obese individual the potassium concentration, per kg of fatfree weight, would be lower than in a light-boned and in a thin subject.

Furthermore, as Forbes and Hursh pointed out, in the newborn the potassium content of the fatfree weight is relatively smaller than in the adult (46 to 52 mEq/kg of fatfree weight vs. 68 mEq/kg). (66)

The authors noted that "it is not known at what point in life the transition from the infantile to the adult state is accomplished" (ibid., p. 259).

Concern with the heterogeneity of the fat-free compartment of the body led Allen, Anderson and Langham to suggest that information on total body potassium, measured on the basis of K^{40}, be used to calculate a smaller body compartment defined as body mass less fat, water and bone mineral. This suggestion, in principle, has merit. The present difficulties in obtaining independent measurements of fat and bone mineral limit the practical value of the suggestion.

Anderson's recent model is three-componental (4, p. 200). It provides for a breakdown of the gross body weight into tissue masses defined in the anatomical, not the biochemical, framework:

$$\text{Body Weight} = \text{Adipose tissue} + \text{Muscle} + \\ + \text{Remainder}$$

The remainder was labeled as the "muscle-free lean body mass".

It should be noted that in the calculation of the adipose and of the muscular components both measured parameters of body composition are used, namely, total body potassium (from K^{40} count) and total body water (from tritium dilution). In other words, the estimates of the two components are not operationally independent.

The Minnesota Model

Metabolic considerations suggest that the first step in the analysis of the body mass requires a differentiation between that compartment of the body which has a relatively important share in the organism's energy metabolism and the relatively nonactive part. (94) The latter compartment includes principally body fat (F), the mineral portion of the bony skeleton (M_O, osseous mineral), and the extracellular water (A_E). By subtracting these components from the total weight of the body (W) we obtain a remainder that has been termed "active tissue mass". We have referred to it as the "cell residue" (C). (34) It contains cellular water (A_C), all protein (P), and the residual mineral (M_R):

$$C = A_C + P + M_R$$

The mineral component of the "cell residue" represents the mineral in the "cells" and in the extracellular fluid, that is, all mineral that is not osseous ($M_R = M - M_O$, where M refers to the total body mineral).

Using this system of symbols, body weight (W) may be separated into four compartments (total body fat, F; extracellular water, A_E; "cell residue", C; and bone mineral, M_O):

$$W = F + A_E + C + M_O$$

Since at present the bone mineral can not be measured directly, the system holds no advantage for the analysis of total body composition, unless we would estimate the "cell residue" on the basis of measurements of total body potassium which, in principle, is feasible.

However, the system is of definite interest for the analysis of the composition of weight changes, in which the bone mineral component may be neglected. Thus weight change can be reproduced by a three-componental model:

$$\text{Weight Change} = F + A_E + C$$

The volume of the extracellular water is determined, its weight calculated, and the "remainder" is separated, densitometrically, into "fat" and "cell residue", with densities of 0.9007 and 1.078, respectively.

We have used this approach in the study of the composition of weight gain (91) as well as of weight loss and of the tissue, accounting for the difference between "lean" and "fat" individuals of the same height and age. (34) The composition of the three types of complex tissue masses, labeled — in the absence of a better term — "obesity tissue", are indicated in Table 3.

TABLE 3

Composition of "obesity tissue" (0), in % (34)

Components \ Conditions	Weight gain	Weight loss	Lean vs. Fat difference
Fat	64	64	73
Extracellular water	14	4	7
"Cell Residue"	22	32	20
Density	0.948	0.954	0.938

These data are essential for the Minnesota densitometric system in which the body weight of a given individual is separated into a compartment identical in density and composition with the "reference body" (R) and into "obesity tissue" (O):

$$W = R + O$$

The "reference body", established on the basis of information on the chemical composition of adult male bodies, supplemented by special considerations of body mineral, was described in Tables 1 and 2. Its known fat content is 15.3 % of body weight, its calculated density is 1.064.

Having determined the density of a given individual, and using the densities of the "reference body" and one of the types of "obesity tissue" described in Table 3, we can calculate the amount of "O", positive or negative, by which a given individual differs from the reference standard. If called for, we can calculate the fat content of this difference, and also the total amount of body fat. The formulas for estimating these components are given in Table 4.

TABLE 4

Formulas for estimating, from body density, the amount of obesity tissue (difference from the reference standard), its fat content, and the total body fat (34)

Component \ Conditions	Weight gain	Weight loss	Static difference
"Obesity tissue"	$\frac{8.696}{D} - 8.172$	$\frac{9.228}{D} - 8.673$	$\frac{7.921}{D} - 7.444$
Fat in "obesity tissue"	$\frac{5.565}{D} - 5.230$	$\frac{5.906}{D} - 5.551$	$\frac{5.782}{D} - 5.434$
Total body fat	$\frac{4.235}{D} - 3.827$	$\frac{4.494}{D} - 4.071$	$\frac{4.570}{D} - 4.142$

The differences in the estimated amounts of total body fat, resulting from the use of the three equations (Table 4) are not large. But the dependence of the composition of "obesity tissue", beyond the effects of sampling, on the conditions under which it is determined, should serve as a warning and as an indication of the variability present in all the biological constants used in the formulas for estimating body composition by indirect techniques. The range of variability of the major "constants", including the density of the "reference body", is only imperfectly known.

Surgeon's Contribution

The simplest model, emerging from the work of Moore et al., (116, p. 29) is three-componental:

$$\text{Body Weight} = \text{Fat} + \text{Body Cell Mass} + \text{"Remainder"}$$

Body fat (F) is estimated from total body water ($F = 100 - \text{Water}/.732$), on the assumption that 73.2 per cent of the fatfree body mass is water. The body cell mass (BCM) may be calculated from the information on the amount of exchangeable sodium, from K^{42} measurements:

$$\text{BCM (gm.)} = K_e \text{ (mEq)} \times 8.33$$

The "Remainder" (R_1) represents the extracellular, non-fat body mass, and can be further divided into extracellular water (A_E, measured by the dilution volume of Br^{82}, corrected for the penetration of red blood cells), red cells (RC, from dilution of red cells tagged with Cr^{52}), and another, smaller remainder, R_2. Expressing all components as weights, we could write

$$\text{Body Weight} = F + BCM + A_E + RC + R_2$$

Finally, the authors derived a formula for estimating the weight of bone (B, dry matrix plus mineral, estimated from the measurements of total body water and K^{42}). Thus the complete "model" of body composition could be written as

$$\text{Body Weight} = BCM + F + A_E + RC + B + R_3$$

where R_3 represents the solids associated with the extracellular fluid and present in connective tissues (dermis, tendons, fascias).

Beyond and outside this framework, More et al. are interested in body hydration (total, extracellular, and intracellular water), plasma and blood volume, and total amounts of exchangeable ions (sodium, chloride, and potassium). (116)

Quantity and Quality

In body composition models the components, including such complex entities as the fat-free mass, are viewed as constant in composition and in density. The "constancy" is only approximative, and the assumed biological constants exhibit inter-individual variations common to all other aspects of the human organism.

This is true for individuals in the "normal" range of variation. The inconstancy of the biological "constants" becomes still more marked under pathological conditions.

The fact that in undernutrition qualitative as well as quantitative changes take place in body tissues has been brought out dramatically by R. A. McCance and his coworkers in the Department of Experimental Medicine, Cambridge University. (153) They succeeded in restricting the food intake of their experimental animals, beginning early in the suckling period, so that at the end of the first year the pigs weighed only 5 to 6 kilograms. This is about 5 per cent of the weight of the well-nourished littermates, weighing by this time about 150 kilograms.

There were remarkable changes in bodily proportions, with the skeleton, especially the cranium, exceeding the growth of the soft tissues. Consequently, the heads became abnormally large in relation to body size. But our concern here is with the soft tissues. The muscles failed to mature chemically. In fact, their chemical development was reversed: they contained in some instances as much extracellular water and as little nitrogen per 100 grams as the muscles of a pig fetus. The subcutaneous tissue was there, but it contained no fat and was filled with aqueous gel.

The presence of qualitative changes, be they associated specifically with alterations in hydration or in the fat content of such tissues as muscles, should be kept in mind especially by those who utilize gross dissection, roentgenography or somatic measurements to characterize the tissue composition of the human body. The presence of changes in the composition of body tissues points to the merit of supplementing the analysis carried out in terms of anatomically defined tissue masses (such as adipose tissue) by the quantitative assessment of chemically defined components (such as fat, as petroleum ether extract).

Surely, in man we shall not encounter the extreme changes in the composition of the body tissues observed by McCance and his colleagues, but qualitative changes take place during growth and aging and are present in individuals varying along the leanness-fatness continuum.

The finding that the water content of adipose tissue in emaciated persons is considerably greater than in well-nourished individuals goes all the way back to Bozenraad's paper of 1911. (15) For abdominal, pericardial and perirenal adipose tissue the values were 31, 33 and 25 versus 12, 18 and 14 %. respectively. (94)

METHODS

In principle, some body components may be measured directly while others must be estimated. The estimates are based on information about related and measurable components, dimensions, or functions of the body.

Body water is an example of a body component that is obtained directly.

Body density or creatinine excretion may be used as an indicator of body composition. If we make certain quantitative assumptions, information about the value of these indicators enables us to estimate the total amount of body fat, the fatfree weight or some smaller, more homogenous compartment.

Finally, we may sample the size of specific body constituents, as when we measure the thickness of the subcutaneous adipose tissue. There are various procedures which enable us to go from measurements of the parts of the organism to total amounts of a given or closely related body component. Special attention has been given to skinfolds as predictors of total body fat or of total adipose tissue. While soft-tissue roentgenograms enable us to measure the thickness of the adipose, muscular and bony tissue, in studies on total body composition the use of roentgenograms was limited largely to the estimation of fatness.

The techniques for measuring body composition have been reviewed, critically and systematically, at a conference held in 1959 at the Quartermaster Research and Engineering Center, Natick, Mass. (36)

Three approaches were described in detail:

1. Direct body measurements (23) and radiographic analysis. (71, 83)
2. Determination of body volume and calculation of body density. (9, 40, 77, 141)
3. Measurement of fluid volumes, electrolyte concentrations, and metabolic balances. (52, 78, 112, 113)

Other conference participants considered bone mineral in reference to estimation of body composition, (1, 7) (see also Moore and Boyden), (115) and the problem of metabolic reference standards, (117, 139) a topic discussed elsewhere by Durnin. (51) Siri presented equations for estimating body fat from body density, from total body water, and from combined data on density and total body water or its extracellular fraction. (142) He also considered, critically, the effects of technical limitations of the methods (errors of measurements) and of the biological uncertainty of the "constants" used in the estimation equations.

Several general reviews of methods for the study of body composition were published in recent years. Forbes covered all the major approaches, including creatinine excretion, with emphasis on isotopic dilution techniques and on the use of whole body radiation counters for determining total body potassium as a predictor of fatfree body mass. (62) Keys and Grande presented the principles underlying indirect methods, with special reference to the densitometric analysis of body composition. (94) The distinction of Pearson's review is in the heavy attention paid to animal studies. (131) While the review is comprehensive in scope, the largest amount of space has been devoted to densitometric procedures. "Recent" advances and developments were discussed by Brožek. (27) References to 19 papers concerned with problems of methodology and presented at the 1963 New York conference on Body Composition were cited in an "Addendum" (ibid., pp. 28—29).

Here we shall discuss briefly the use of body measurements, direct and radiographic, body density, total water and its fractions, and concentrations of electrolytes, especially the "exchangeable" and "total" potassium. Reviews of the information obtained by direct analysis will be noted.

Direct Analysis of Human Bodies

It is universally recognized that the direct analysis of whole human bodies provides the final criterion against which the indirect approaches must be validated. Yet the relevant information is meager. While it is understandable that human anatomists turned in their research to pastures greener than topographical anatomy, it is regrettable that the structure of the whole organism, considered in terms of tissue masses and chemical composition, has remained a relatively neglected field. (22)

The available information on man was summarized by Widdowson. (154) The literature on the chemical analysis of human as well as of animal bodies was reviewed in detail by Widdowson and Dickerson. (155) They considered the composition of the body as a whole as well as the composition of the organs and tissues. In addition to the composition of adult man, the authors describe the chemical development of the fetus and of the body between birth and adulthood.

Direct analysis of the body composition of infants of diabetic mothers revealed a higher fat content than was found in infants born to non-diabetic mothers. (56) In both groups the infants which were studied had died in the immediate neonatal period or were still-born. The composition of the fatfree weight in the two groups was not different.

Balance Studies

In principle, metabolic balance studies, performed continuously or serially between two specified ages, provide the basis for an accurate calculation of the changes in selected aspects of body composition, such as protein content (from nitrogen balance) and skeletal mass (from calcium balance). Fomon and Owen set down reasons for the failure of such calculations to provide precise, valid estimates of changes in body composition. (60) Nevertheless, the methods are regarded as useful when only relative results are sought, as in the nutritional evaluation of two diets fed to comparable groups of infants at identical intakes of nitrogen, or in comparing the performance of normal subjects with individuals having certain metabolic abnormalities.

Somatometry

The use of body measurements, including skinfolds, for the anthropometric (somatometric) analysis of body composition has been discussed in several contexts. (21, 23, 25)

The number of potential sites at which skinfolds can be measured is large. The selection of a finite number of such sites can be based on a variety of criteria, such as accessibility or contribution to the prediction of total body fat. Lewis et al. (101) obtained data indicating that one could reduce the number of sites from 36 to 6. The observations were made on members of a British North Greenland Expedition. Skinfolds were measured at 36 sites, at monthly intervals, for about 2 years in a group of 24 men, with the aim to characterize changes in subcutaneous fat and their relation to body weight. Statistical analysis of the data indicated that six sites would represent adequatly the whole body surface. Two of the sites were located on the limbs (upper arm, upper thigh), two on the front of the torso, and two on the back. The selection was made in terms of the following criteria: practicability, anatomical representativeness, sensitivity to changes in fat depots, and reproducibility. Mean values of the six chosen sites were in good agreement with the means for all 36 points. Actually, one of the 6 sites. on the lower back, esentially duplicated the subscapular value and could be eliminated, thus reducing the "minimum" number of sites to five.

Fletcher (57) measured skinfolds at nine sites and estimated the total body fat (F) from skinfolds (corrected for the thickness of the skin, averaging 2.0 mm in men and 1.8 mm in women) and height:

$$F = (\text{Sum of 9 fat folds}) \times \text{Height}^2 \times 0.1,$$

where the fat folds are in millimeters, height in meters. The values of body fat estimated from total body water correlated highly ($r = 0.92$) with the somatometrically estimated "total depot lipids".

Skinfolds, as well as linear and circumferential body dimensions, single and combined, may serve as predictors of body density. Body density, in turn, allows separation of gross body weight into its fat and non-fat component.

In Czech children, the sum of 10 skinfolds correlated with body density as follows: in boys, age 9 to 12, $r = -0.896$, age 13 to 17, $r = -0.916$; in girls, age 9 to 12, $r = -0.811$, age 13 to 17, $r = -0.833$. The site which yielded the highest correlation with body density varied with age and sex. (125)

The validity of predicting total body fat from body measurements and somatotype ratings, with densitometric estimates used as the criterion of fatness, was re-examined by Damon and Goldman. (48) In a sample of young athletes, the triceps and subscapular skinfold yielded the closest approximation of the "true" fat content of the body. It is of interest that these sites are the ones selected most frequently for measuring skinfolds.

Behnke approached somatometric fractionation of body weight on the basis of measurements of circumferences and diameters. (10) Skeletal measurements, proposed by Behnke for the estimation of lean body mass, were obtained — either directly or on roentgenograms — in a sample of young women, together with data on body density and total body water. (160) Correlations between the values of fatfree weight, yielded by the Siri formula in which density and total body water are combined, and the anthropometric estimates of the lean body mass were disappointingly low (r = 0.362 to 0.622).

Detailed analysis of the interrelations between various indicators of body composition revealed that in older women the single body measurements most closely related to body density were a chest skinfold (at the axilliary border, over the pectoralis major; r = —0.716) and the abdominal circumference at the level of the umbilicus (r = —0.717). (157, 158, 159)

Equations were provided for estimating body density from skinfolds, from circumferences and diameters alone and from combined measurements. The corresponding coefficients of multiple correlation were 0.818, 0.845 and 0.903, respectively. Empirically, the most effective combination of predictors of body density appeared to include a skinfold (to the right of the umbilicus), abdominal circumference (at umbilical level), and the bideltoid diameter; the associated multiple correlation coefficient was R = 0.821.

Roentgenogrammetry

Roentgenograms of the limbs, obtained with "soft-tissue" exposure, make it possible to measure the width of the adipose, muscular, and osseous components. (71, 148) Certain sites, such as the trochanteric site, yield useful information on the thickness of the subcutaneous adipose tissue, not obtainable by skinfold calipers. Garn outlined a procedure for estimating the total amount of the adipose tissue in the body on the basis of correlations between the radiographic thickness of the adipose layer and body weight. (70) Brožek and Keys developed equations for estimating body density (and thus total body fat) from radiographic measurements of subcutaneous adipose tissue. (34)

In young women, the fat pad measured at the iliac crest showed a higher correlation with the specific gravity of the body (r = —0.709) than did any of the other twelve sites. (161) The correlation of the sum of thirteen fat pads showed only a slightly closer relationship (r = —0.742).

Potassium as a Body Composition Parameter

The concentration of electrolytes in the human is of both biological and medical interest per se. In addition, body potassium — largely intracellular in its distribution — is a valuable indicator of gross body composition.

Two approaches were developed for assessing the potassium content of the living body: 1. Dilution of the isotope K-42 (14, 52, 113), and 2. Measurement, in whole-body counters, of radioactivity due to the presence in the human body of the naturally occurring potassium isotope, K-40. (4, 5) The problems involved in measuring accurately the potassium content of the body from K^{40} are large. (111, 134) Forbes considered the nutritional implications of the advances in instrumentation, which make it posible to measure very small amounts of radiation emanating from the human body, including K^{40} radioactivity. (63) The fact that no injection of any substance into the body is required, represents an obvious advantage over K^{42} dilution methods.

Densitometry

Recent publications were concerned both with methods of measuring body volume, needed to calculate body density, and with interpretation of whole-body density as an indicator of body composition.

In contrast to the usual emphasis on the constancy of the "lean body mass", Wedgwood emphasized the need to study the changes in this body compartment taking place in the course of growth, maturation, and aging. (150)

As regards methods applicable in the laboratory and in the field, (2) the measurement of the mass (and volume) of water displaced by the fully submersed body is both accurate and fairly simple. The principal complication is the need for measuring the amount of air present in the lungs and respiratory passages at the time the underwater weight of the body is read off the scale. (77) Garn and Nolan described a procedure involving not weighing the subjects under water but directly measuring the volume of displaced water. (73) The paper does not mention a method for correcting the gross body volume for the air in the lungs and respiratory passages.

This problem is not present when body volume is determined by helium dilution, the most promising "dry" technique. (141) But there seems to have been a plethora of technical problems, related in particular to the accumulation of carbon dioxide and the increase in the temperature of the main chamber. (45, 145) Amatneek et al. were plagued by additional problems, in part because they wished to measure the body volume of obese individuals and needed, consequently, a large chamber for their subjects. (3) The method has been adapted successfully to determine the body volume in infants. (59) A photogrammetric method for the determination of body volume was outlined by Pierson. (132)

An alternate "dry" approach involves various versions of the air displacement technique. (55, 67, 102) Gnaedinger et al. reported a distressingly low coefficient of correlation (r = 0.36) between the densities based on air displacement and on underwater weighing. (75) Hix et al. compared the techniques of measuring body volume by air displacement and by helium dilution. (82) The r's reported for "specific gravities" were very respectable: 0.96 for men and 0.91 for women. The major sources of error in the air-displacement method were identified as changes in temperature and relative humidity in the chamber, and inadequate precision with which the pressure was reached.

Hydrometry

Techniques based on the dilution principle have long been available for measurement of such "spaces" as the extracellular space, even though the estimation of a "true" (absolute) extracellular space still poses serious problems. These techniques are particularly useful when we wish to quantify changes in extracellular water, expressed as a percentage of body weight or of total body water. The development of techniques for the measuring total body water represented an important step in the analysis of body composition. The early conceptual and procedural developments were described elsewhere. (92) Deuterium oxide, D_2O, and, more recently, tritium, THO, have become the solutes of choice.

The methods for measuring body water and electrolytes were described and discussed by Edelman, (52) Moore, (113) and Silver (140) among others. Total body water (and some of its fractions, especially the extracellular water) is of interest on its own account, as a large component of total body weight. More importantly, it serves (alone or in combination with such other measurements as body density or average potassium concentration in the body) as a basis for estimation of the fatfree body mass (or its fractions) and of its complement, body fat.

It may be recalled that in separating total body weight into fat and the fatfree body mass on the basis of total body water, one assumes that the water forms a constant fraction of the fatfree mass. In "normal young men" such an assumption is a tolerable approximation. In the presence of excess hydration, combined measurements of total body water and of extracellular water could yield a more reliable estimate but the practical difficulties loom large. (142, p. 241)

During growth the hydration of the body is changing, and any single formula for estimating fatfree mass and total body fat cannot be valid. (150) These conditions call for a direct determination of total body fat by techniques such as that involving the use of inert gases, highly soluble in fat. (100) Unfortunately, the inherent complications of the technique limit severely its application.

SOME APPLICATIONS

Like all scientific techniques, the methods for the analysis of body composition are potentially useful tools, not goals in themselves. They enable us to examine organisms, including man, in terms of new "dimensions". (25) But their scientific value resides in their contribution to the solution of biological, medical and agricultural problems.

Concern with the genesis and the significance of individual differences in body composition was present from the very outset. Thus Matiegka's early endeavor to devise a system for estimation of tissue masses on the basis of external body measurements had its roots in his quest for a comprehensive, quantitative characterization of man's nutritional status. (26, 109) Densitometric analysis of body composition was applied by Kohlrausch, 35 years ago, to the study of the effects of exercise. (96, 97) Behnke's interest in body composition developed in the context of applied physiology, with special reference to deep sea diving, (8) and one of his earliest densitometric studies was devoted to the body compositions of athletes. (151) F. D. Moore and his colleagues became interested in body composition around 1940 in conjunction with treatment of patients who had been badly burned. Their work remained clinically oriented. Its history was briefly reviewed by Moore. (112, p. 135—139) At the Laboratory of Physiological Hygiene, University of Minnesota, work on body composition was stimulated, in 1944, by the need for quantifying the changes expected to take place in the course of prolonged semistarvation and subsequent rehabilitation. (18) The results were reported, in detail, in a collaborative monograph. (93)

Brock stressed that underfeeding, overfeeding, or unbalanced feeding affects not only the external morphology but also the relative size of various tissue and fluid compartments of the body. (17) He regards information on nutrient reserves (see Passmore) (130) as being of great theoretical and practical interest to the nutritionist. While techniques for the analysis of body composition, especially the somatometric approach, are especially relevant for human nutrition, the field of application of these techniques is broad and exceeds the compass of traditional nutrition research. (72) In our review of the literature, focused on the period from 1953 to 1961, the following topics were discused: functional and pathological correlates of body composition [see also Bjerulf (13) and Parnell (128)]; sex, growth and aging; physical activity; and loss and gain of body weight. (24, 28)

Pearson, in a review centered on methods, stresses the wide usefulness of the analysis of body composition, in vivo, from detached studies of the differences between ethnic groups to practical research concerned with human health and animal husbandry. (131) Yet students of animal nutrition still tend to be satisfied with the gross criterion of weight gain, leaving untapped the resources available in the form of direct and indirect analysis of body composition. In addition to their relevance for the evaluation of nutritional and energy value of domestic animals, Pearson considers the potential usefulness of compositional methods in the context of marketing farm animals and selecting animals of superior muscle development for breeding purposes. And there is, of course, the broad spectrum of problems concerning the effects of hormones and other physiological factors.

Numerous potential implications of compositional techniques in physical anthropology and in the wider area of human biology were brought out by discussants commenting on a review of somatometric methods for characterization of body composition. (25, 29)

Proceedings of the London conference on body composition (33) contain systematic reviews of the literature on sex differences (103) (see also Nagamine and Suzuki), (118) body composition in normal adults, (122) hydrometric analysis of changes during growth and aging, (68) and the effects of physical activity. (127)

At comparable levels of overweight—underweight, the less physically active railroad clerks tend to have more fat, in terms of skinfold measurements, than the more active switchmen. (37) In male college students, at a given gross body weight, the lean body weight calculated from K^{40} activity was about 10 per cent higher in the "active" than in the "non-active" group. (137) Jokl considered the interaction between diet and exercise as factors in body composition in a recent monograph. (87) In adolescent children, five months of fairly intensive physical training resulted in a significant decrease of the fat content and an increase in the fatfree body weight. The gross body weight remained constant. (86)

Changes in body composition were studied in pregnant women. (138) Several recent studies have been concerned with the body compositions of infants (46, 56, 61, 80, 88, 124) and with changes in disease.

The clinical implications of research on body composition were spelled out by Moore. (114) The extensive monograph by Moore and his colleagues is devoted to the study of body composition in a variety of disease states. (116) In addition to the sections on methodology, nutritionists will be especially interested in the chapters on "Chronic Wasting Disease and Anabolic Recovery" (pp. 173—223) and on "Obesity" (pp. 461—482).

The authors underscore that the study of body composition of obese individuals should provide information not on one but on two points: first the extent of obesity, defined as the relative amount of depot fat; second, the composition (and "health") of the remainder, the fat-free body weight, which in research on body composition is typically regarded as "constant". Moore et al. (116) view as crucially important the relation between the size of the cellular "engine" of the body (the body cell mass) and the size and composition of the extracellular supporting structures (extracellular tissues). In these terms the authors differentiate between "healthy" and "unhealthy" obesity. More precisely, we should speak of obesity associated with a "healthy" or "unhealthy" fatfree mass.

The individuals of the first type are obese but vigorous and functionally effective. As one would expect, their total body water is small in comparison to their body weight. But their cellular mass is well developed, as shown by a high ratio of the intracellular to the total body water.

By contrast, individuals with "unhealthy" obesity (ie., with an unhealthy fatfree mass) show changes in the aqueous phase of the body which we usually associate with wasting: a low intracellular to total body water ratio, and an associated elevation of the ratio of exchangeable sodium to potassium.

Changes in body composition in undernutrition have been described by Keys (90) and Grande. (79) Older data on body composition under conditions of protein-calorie malnutrition, yielding the clinical syndrome of kwashiokor, were summarized by Waterlow et al. (149) The topic was recently taken up by Hansen, (17) Garrow, (74) and Dean. (50) Hansen (ibid.) showed that during recovery from kwashiokor the principal change is the reduction of extracellular water, paralleled by an increase in intracellular water — an indication of tissue growth.

Growth

Changes in body composition associated with growth are complex (43) and not readily measurable, with precision and dependability, by the indirect methods. Available data will be presented systematically in a textbook on "Human Development". (123).

If viewed in a broad-enough perspective of time, body composition does not maintain a truly "steady" state at any phase of the life cycle. However, the changes during childhood are more rapid and more marked than in adulthood. Profound changes take place during and following the period of sexual maturation when in the boys the fatfree mass, in the girls the body fat develop rapidly and closely approach the sex differences characteristic of adult men and women. (81, 84, 120, 126, 162) Plotting lean body mass/height ratios against time brings out especially clearly the sex differentiation as a function of age. (64, 66)

Maresh obtained interesting data from roentgenograms of the calf, thigh, and forearm of a boy studied from birth to the age of 17 years. (108) While not expressed as total amounts of the given tissue in the body, the data show clearly two waves of fattening, with a first maximum at 1.5 years and a second, less impressive peaking at 11.5 years (see also Maresh). (107)

Tanner presented similar results obtained in the Oxford Child Health Survey. (148) More importantly, he related the changes in bone, muscle, and "fat" of boys and girls in such a manner that the individual growth-curves were aligned in reference to the time of the fastest growth in stature ("peak height velocity"). The data on yearly gains in bone, muscle and "fat" widths were given for boys and for girls, for 2.5 years prior and for 2 years following the period in which the "peak height velocity" was reached.

Numerous studies portray the age trends in the subcutaneous fat of children in different parts of the world.

The problem of changing body composition by diet, with special reference to human growth, was reviewed by Forbes. (62)

Aging

Changes taking place in body composition during maturity and beyond are a part of the complex of processes constituting "aging". Some of the reports on growth go beyond adolescence and merge with the work of the students of gerontology. This is true of Friis-Hansen's systematic review, based on hydrometry, (68) and of individual studies, especially those based on K^{40} determinations (66, 110) and skinfold measurements. (85) Comstock and Livesay obtained data on sex, race and age differences in subcutaneous fat on the basis of photofluorograms made in a mass chest X-ray survey. (47) In agreement with available information, females at all ages had more subcutaneous fat than males. Among white males, the subcutaneous tissue at the trapezius site increased in thickness to about 40 years of age and remained relatively constant thereafter; at the flank site there was a slight tendency toward further increase into the sixties. Among females, at both sites the thickness of the subcutaneous adipose tissue continued to rise fairly steeply into the fifties, when it began to decrease.

Other studies were limited to adult subjects, male (69, 119) and female. (152, 158, 159) In their study of the body composition of the Chinese on Taiwan, Chen et. al. were forced by the limited size of their sample to group their subjects as "young men", "middle-aged men", and "women". (44)

Edelman reviewed the data on total body water in reference to the total life span. (53) The data on electrolytes (potassium, sodium, and chloride) refer to three age groups for adult males, two age groups for adult females.

Available information on the relative amounts of total, extracellular, and intracellular water and of total body fat was summarized in tabular form by Friis-Hansen (see Table 5).

TABLE 5

The relative amounts (percentages of body weight) of total body water, its extracellular and intracellular fractions, and total body fat. From Friis-Hansen (68)

Age	Total	Body water		Fat
		Extra-cellular	Intra-cellular	
Fetus, 1 mo.	94			
Fetus, 5 mo.	87	62	25	1
Fetus, 8 mo.	81	52	29	4
Newborn	77	44	33	15
1 month	73	39	34	16
2 months	70	33	37	20
4 months	67	30	37	24
6 months	63	28	35	26
9 months	61	27	34	28
1 year	60	26	34	29
2 years	63	28	35	25
3 years	63	27	36	24
6 years	62	26	36	22
9 years	62	26	36	20
12 years	61	25	36	18
18 years*	65/54	26/25	39/29	15/28
25 years	59/51	25/24	34/27	20/30
45 years	56/49	25/24	31/25	24/33
65 years	53/47	25/24	28/23	28/36
85 years	50/45	26/24	24/21	32/40

* First values of all double entries refer to males, the second values to females.

The study reported by Lesser et al. suffers from the small size of the samples and a failure to separate the data for males and females. (99) It has the great methodological advantage that body fat was measured directly, by prolonged absorption of inert gases (cyclopropane, krypton, or their combination) from a closed respiratory system. Thus the fatfree mass could be obtained simply by subtraction (gross weight less the weight of the fat), without assumptions as to its composition. The fatfree body mass was analyzed in terms of its water content. The decrease in the relative amount of intracellular water, observed by Lesser et al., (99) may be regarded as a genuine characteristic of aging, indicating a loss of "active tissue". This loss is paralleled and balanced out by a tendency toward an increase in total fat. (19)

These observations have been confirmed and extended by Oberhausen and Onstead who made K^{40} measurements in a very large sample of "normal" persons. (121) Similar age trends were reported by Lorimer et all. on the basis of measurements of whites (338 femals, 361 males) and Negroes (121 females, 97 males). (104) Their data on age changes and sex differences in the potassium content of the body (g K/kg body weight) are reproduced in Figure 1.

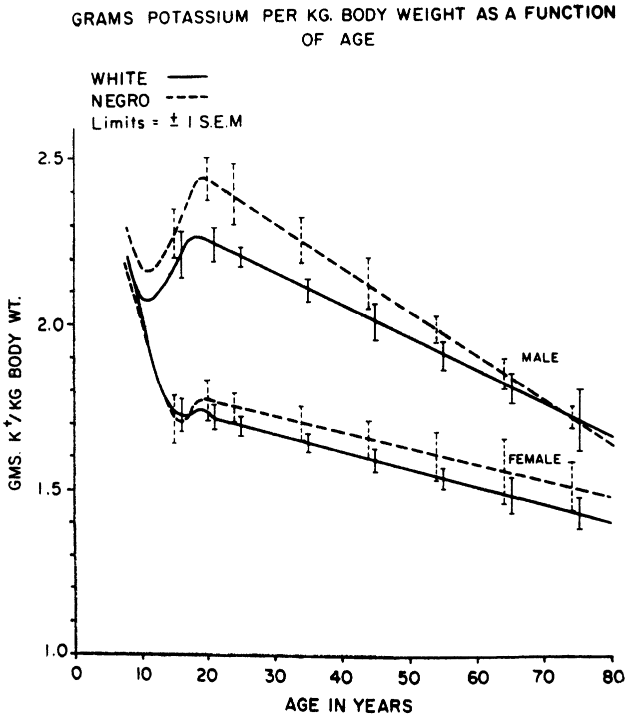

FIGURE 1

Changes in Potassium Concentration (g/kg body weight) as a function of age[104]

As regards racial comparisons, Negro males have a higher average potassium concentration than white males. The difference decreases wih age. Negro females also have higher average K concentration than white females, but the difference remains almost constant after adolescence.

In regard to the age trends, Oberhausen and Onstead noted several interrelated factors. (121) In females, potassium concentration decreases continuously with age. The initial decrease during childhood, present in both sexes, is interpreted as reflecting a decrease in the intracellular potassium concentration. In adulthood, the further decrease in potassium concentration in the body is accounted for by the steady increase in total body fat. In males, the rapid muscular development during adolescence results in a marked elevation of the potassium concentration. As in the females, the subsequent decrement is related to the accretion of fat and to a gradual replacement of the fatfree body mass by fat.

Weight Changes

The compositional techniques find an important application in the analysis of the changes — increments or decrements — of body weight induced by dietary treatment. (129) The analysis may be carried out in various ways, including those based on measurement of extracellular water and on densitometry; (34, 91) measurement of total body water and nitrogen balance (see also Kyle et al.); (98) and nitrogen balance and energy balance. (78) The methods have in common the assumption that the carbohydrate stores of the body remain approximately constant and that changes in bone mineral can be ignored.

Berlin et al. calculated cumulative fat loss in patients undergoing weight reduction in 4 days: 1. from nitrogen balance alone, 2. from nitrogen balance and body water, 3. from the nitrogen, sodium and potassium balances, and 4. from the body water — body density data. (12)

We have studied, in collaboration with our colleagues in the Laboratory of Physiological Hygiene, University of Minnesota, weight changes in the presence of prolonged caloric deficit, (93) brief but severe calorie deficit, (36) and positive calorie balance. (91) The data were summarized by Keys and Grande (94) who cite the literature reporting the results obtained in the course of weight reduction of obese individuals. This topic has been studied recently by several authors who combined dietary restriction with exercise. (41, 76, 127) Rath and Slabochová regard physical exercise as an important feature of an effective weight-reducing regimen, in that it facilitates fat loss while sparing body protein. (133)

Two studies on weight gain will be discussed in greater detail.

Skinfold measurement, as a simple bed-side technique, was used to study the response to therapy in patients with malabsorption syndrome. (58) Total body fat was estimated from skinfolds and height. (57) The initial body weight of 39 patients with malabsorption averaged 76 % of the "expected weight", with individual values ranging from 56 % to 92 %. In 29 individuals whose weight rose to within 20 % of the "expected weight", on the average 50 % of the weight gained was fat, with the figure tending to be higher in women (68 %) than in men (46 %).

Russel and Mezey studied the composition of the tissue laid down by four female patients with the syndrome of anorexia. (135) At the outset, body weight ranged from 58 to 75 % of "normal" weight. The patients were persuaded to consume liquid diets high in caloric value for five to six weeks and gained weight rapidly (from 5.6 to 11.8 kg). During this time they resided in a metabolic unit. Their caloric expenditure was estimated on the basis of daily records of activities (sleeping, lying down, sitting, walking) the metabolic cost of which was determined twice weekly. The total daily energy expenditure was obtained by adding up the contributions of each type of activity during 24 hours. It was estimated that, on the average, a surplus of 7500 calories was required for a gain of 1 kilogram body weight, with a range from 6,900 to 8,200 calories per kg of gain in the four patients.

What is the composition of this gain? The proportions of fat, protein and water in the tissues laid down were ascertained from the data on the cumulative nitrogen and calories balances. The water content of the gain was obtained by difference (water balance = weight gain — weight of the synthesized protein — weight of the synthetized fat). The data are indicated in Table 6.

TABLE 6

Composition of the weight gained by patients with anorexia nervosa (Table 4 in Russel and Mezey) (135)

Patient number	Weight gain, kg	Cumulative nitrogen balance, g	Calories available for fat deposition
1	11.805	72.0	89.400
2	7.100	85.1	46.100
3	7.390	118.8	49.100
4	5.590	98.3	42.200

Patient number	Protein synthesized,		Fat deposited,		Water balance,	
	g.	% wt. gain	g.	% wt. gain	g.	% wt. gain
1	450	4	9.615	81	1,740	15
2	533	8	4.950	70	1.610	22
3	743	10	5.270	71	1.370	19
4	614	11	4.600	82	380	7

On the average, the new tissue deposited in the course of feeding contained 77 % fat, 7 % protein, and 16 % water. Data on skinfolds, measured at five sites, confirmed a rapid rise in body fat during the period of positive calorie balance.

CLOSING COMMENTS

Anything new under the sun?

Contrary to the wisdom of ancient proverb makers, research on body composition provides full justification for giving a positive answer to the above query: the use of indirect methods for the study of body composition represents a radically new development in the scientific study of "inner man". Elsewhere we wrote of quantitative description of body composition as physical anthropology's "fourth dimension", although a "third" dimension may have sufficed. (25) The concern with volumes and weights of tissue and of their chemical components, summed for all organs of the body, constituted a significant step forward, in contrast with the anthropologist's traditional emphasis on linear body measurements.

Innovations in method

Development of equations for estimating the weight of relatively homogenous body components from body measurements, quantification of soft-tissue roentgenograms, use of density as an index of the fat content of the body, development of dilutional techniques for the assessment of total body water and its fractions, isotopic determinations of exchangeable electrolytes — all of these represented genuine advances in methodology.

Moreover, the search goes on. The possibilities of ultrasonic tissue analysis are being explored in man. (89) Direct measurement of total body fat by simultaneous absorption of two inert gases has been accomplished. (100) The estimation of the potassium content of the living human (and animal) body by measuring K^{40} radiation in "whole-body counters", though not free of difficulties of measurement and interpretation, has pointed to a whole new horizon for research on body composition.

K^{40} is a potassium isotope that occurs naturally in the body. K^{42} is one of the man-made isotopes introduced into the organism for purposes of measurement. The newest, potentially significant approach to the isotopic analysis of body composition involves neutron activation. It has been known that radioactivity can be induced in certain materials, *in vitro*, by irradiation with neutrons. In turn, measurements of the radioactivity of the specific elements make it possible to estimate the amount of each. Anderson et al. applied the technique of neutron activation to man, *in vivo*, and estimated the total amount of sodium, chlorine, and calcium in the body. (6) The possibility of using this technique for the determination of total calcium is particularly intriguing as an avenue to a more direct estimation of bone mineral. It should be noted that the radiation doses received by the experimental subjects were small, not exceeding those used in diagnostic radiology.

"We have the techniques, where are the facts?"

These are the words with which A. R. Behnke ended his closing remarks at the 1963 New York conference on body composition. (11) They were meant not as a detached appraisal of the "state of the art" but as a road to further research.

Since Behnke can view the field from a perspective of a quarter of a century of labor on the body composition ("samotolytic") vineyard, it may be proper to list the projects on the planning board as he sees them: a) "multiply the three chemically analyzed cadavers by 10, and then 30 and 100; b) apply physiochemical techniques to the body as a whole post mortem (and this includes densitometry, anthropometry, radiography) and to the molecular analysis of tissues — let the dead in fact teach the living but in the language of 'space' technology; c) implement the search for lipophilic substance aimed at 'direct' measurement of body fat and, also, augment tracer and other techniques for quantitation of mineral, bone, protein, and vital cell moieties as mitochondria; d) determine, in biopsies of adipose tissue and in discrete 'fat' bodies, cell number utilizing DNA content as an index; e) apply the multidisciplinary tools of corporeal assessment at our command to sizeable groups of healthy subjects who vary greatly in size, shape, fatness, and muscularity — this will provide us with a reference man or body determined analytically, not forensically; and f) lest we forget, regulate and assess physiologic data of our subjects with due regard for such parameters as fluid and mineral intake, diet, exercise, and even rest — reliable data do not accrue from the 'man in the street', but rather from the man in the ward."

Other investigators will formulate for themselves additional challenging tasks, (114) including those which have direct and specific relevance to human nutrition studied in the laboratory, in the clinic, and in the field.

Some of these tasks will be narrow in scope and may be approached with simple tools. The phenomenon of skinfold compression and its relevance for skinfold measurement represents such a restricted reseach topic. On a limited sample we have shown that compressibility of skinfolds decreases with age and varies between different body regions. (38) Skiba confirmed that in the same individual the skinfold compressibility varies in different body regions and pointed out the presence of impressive variability between individuals. (143) The phenomenon is affected also by the physical activity of the subject. Additional information on age and sex differences and the effect of other factors is needed.

The fat content of subcutaneous adipose tissue at a given site but varying in thickness is another problem on which the presently available information is inadequate. Is this a world-shaking problem? No, but it is directly relevant to the interpretation of skinfold measurements.

Intermediate in complexity and time investment are studies on obesity, with special reference to effective weight reduction and to maintenance of the loss achieved, and the broad area of investigation on the effect on body composition — in infants, children, adolescents, and adults — of such factors as the composition and amount of food eaten, feeding frequency, and physical activity.

There are problems that call for long-term study, with all the complications inherent in longitudinal research. The significance of differences in leanness-fatness in middle-aged individuals, evaluated in reference to their proneness to degenerative diseases, especially atherosclerosis, belongs into this category. (95) Still more difficult and more challenging is the apraisal of the potential significance of differences in growth rate and in body composition of infants and children, evaluated in terms of morbidity during adult life and of longevity.

Finally, there are issues in "nutritional anthropometry" which may be regarded as genuinely world-shaking (especially if the population explosion goes on unchecked) and which are, in any case, world-wide: Can we develop, within the framework of the World Health Organization, a system of measuring and reporting which will allow us to monitor the nutritional status of the world's population? Clearly, the measurements to be used must be minimal in number in order to make such an operation feasible, especially since the problem calls for periodical, repeated measurements on the samples of a given population. Nevertheless, one could hardly revert to gross body weight as t h e criterion of human nutrition.

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