Journal of the Minnesota Academy of Science

Volume 30 | Number 2 Article 2

1963

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In the past, physical anthropologists centered their interests on the skeleton. Courses in osteology flourished throughout the country's anthropological departments. This enthusiasm for skeletal material could be well understood if human evolution and the associated problems are taken into consideration. Further, skeletal remains were always in plentiful supply and the numerous measurements coupled with many indices of each bone provide an absorbing study for the classical physical anthropologists.

The results, however, are exactly what was asked for i.e. dimensions of bones. An interpretation of these results in terms of sex, race differences is unwise. First, the dimensions overlap in many cases and second, it should be born in mind, that nutrition, climate, physical activity as well as pathology may have marked influence on the growth of the bone.

The measurements on living man were partly influenced by the interest of physical anthropologists in the assessment of bodily form and its differences as far as age, sex and race are concerned. The classical tools used for anthropometrical measurements such as steel tape, sliding compass and spreading calipers did not lead to anything else but the measurements of bony diameters or circumferences of either head, chest, limbs. These measurements were usually supplemented by visual observations of form and distribution of hair, eye color, eye folds, form of the nose, lips, etc. Sheldon's (1940) body typing is a good example of visual inspection even though photographs were used for characterizing the different degrees of endomorphy, mesomorphy and ectomorphy.

Although these statements oversimplify the issue, it is true that the core purpose, the study of man as a whole, somehow escaped the anthropologist's mind for great many years. Only recently, the study of man's body compartments forming today a flourishing and challenging field of body composition, gave physical anthropologists new insights into the complexity of the changes in body compartments should they occur during growth or aging, under different nutritional or physical activity regimens, under different climatical conditions, altitude, or should such changes occur due to the pathological conditions in disease.

From a historical point of view it is only fair to mention Matiegka (1921), the Czech anthropologist who already, forty years ago, tried to point out the broad avenue of somatometric evaluation of man's physique for purposes of life insurance examinations, choice of athletic events, choice of properly suited vocation, etc. Physical anthropology, physiology and psychology were combined in a happy marriage in his approach. Matiegka's goal was to give physical anthropology broader spectrum of dynamic field based on studies of man's work capacity and his health.

Metiegka proposed four components into which the gross body weight (W) was partitioned: $W = O + D + M + R$

where O = the weight of skeleton, "ossa," (bones)
D = skin ("derma") plus subcutaneous adipose tissue
M = skeletal muscles, and
R = remainder

Anthropological measurements provided the necessary information for estimation of the first three components. Detailed discussion of the approach for quantitative appraisal of human morphology by Matiegka is worthwhile reading for any interested student of physical anthropology.

Before discussing the numerous methods used in studying body composition it is necessary to point out the several ways to approach the problem. We can think about partitioning the body from the point of an anatomist or a physiologist. The anatomical frame of reference can be twofold – direct dissection or direct chemical analysis of cadavers. The physiological reference is taking into consideration indirect analysis *in vivo*. The following table exemplifies well the different "frames of reference."

TABLE I

Anatomical	Chemical (Direct analysis of cadavers)	Biochemical (Indirect analysis *in vivo*)
Adipose Tissue, Skin	Fat, (*ether extract*)	Fat (*estimate*)
	Total body water (*by dessication*)	Total body water and its fractions (*by dilution*)
Muscles, Viscera	Protein (*6.25 × nitrogen*)	Cell mass (*estimate*)
Skeleton	Total and bone mineral (*ash*)	Bone mineral (*estimate*)

The question arises now how to estimate or measure the total body fat, water, muscle, bone, and where the first information about the magnitude of these compartments came from. German anatomists were the first to be concerned with quantitative analyses of adult bodies. Modern chemical data from cadavers applicable to body composition were supplied by Mitchell *et al.* (1945), Widdowson *et al.* (1951), and Forbes *et al.* (1953). The following table presents the body composition of the female cadaver studied by Widdowson *et al.* and that of the adult man studied by Forbes *et al.*

In order to bridge the direct analyses of the cadavers with the indirect methods as they apply to living man, it is necessary to return for a moment to the classical anthropometry before advancements to the most modern biophysical and biochemical methods will be presented in a short review.

Indirect Studies of Body Composition: Traditionally, heights and weights were taken on living subjects not only by physical anthropologists but also by physicians, physical educators, etc. The shortcomings of weight determination is obvious if one asks a simple question — what does this weight consist of? Subsequent measurements of circumferences of the limbs, chest or diameters of the bones are helpful but very limited indicators of "robusticity" or gracile structure of the subjects. All these measurements fall under the title of "Surface Anthropometry." Only the introduction of skinfold calipers for estimation of subcutaneous fat (about 50% of the total body fat) plus estimate of musculature according to the formula:

$$d^1 = c/\pi - S$$

where d^1 = corrected diameter of the limb measured

c = circumference of the limb measured (with a steel tape)

$\pi = 3.1415$

S = skinfold measured at the same site where the circumference was taken, helped to estimate, in part only, some of the tissues found under the skin.

TABLE II

Age	Sex	Height in am	Weight in kg	% Total Weight Water	Fat	Protein	Ash	% Fat-Free Weight Water	Protein	Ash
42	F	169.0	45.1	56.0	23.6	14.4	5.8	73.3	19.1	7.6
46	M	168.5	53.8	55.1	19.4	18.6	5.4	68.4	23.1	6.7

Roentgenograms and Ultrasonic Measurements of Subcutaneous Fat: Once the interests of students in body composition was aroused it was natural that new methods will be sought for better estimations of the compartments than "Surface Anthropometry" could offer.

Subcutaneous fat, being a superficial layer, can be seen as well as measured on radiographs. The detailed treatment of the soft-tissues roentgenograms came from Garn *et al.* Fels Research Institute (1957) and Brožek *et al.* (1958). The X-ray measurements are very helpful for determination of the subcutaneous fat deposits where the skinfolds cannot be measured. Further, information is also provided about muscle and bone.

Most recently, ultrasonic visualization for diagnostic purposes on human subjects proved very successful. The observations are not based on shadow pictures as in roentgenograms but are based on cross sections built up from echo information over a period of time when scanning system is used. The advantage of ultrasonic method lies in the identification of surfaces as compared to thicknesses of a section obtained from soft-tissue roentgenograms.

Estimation of Body Density: As the human body can be compartmentalized in several ways, depending on the purpose of the study, determination of body volume and body density permits to divide the body into a two-component system i.e. fat and fat-free mass according to the equation:

$$M = M^1 + M^2$$

where M^1 = Fat

and M^2 = Fat-free mass

Thus, if the densities of the two components are known, the density of the system can be determined empirically allowing the calculation of the masses of the two-component system.

$$D = \frac{M^1 + M^2}{\frac{M^1}{d^1} + \frac{M^2}{d^2}}$$

if $M^1 + M^2 = M = 1$

then $$D = \frac{1}{\frac{M^1}{d^1} + \frac{M^2}{d^2}}$$

solving for M^1 yields:

$$M^1 = \frac{1}{D} \cdot \frac{d^1 \times d^2}{(d^2 - d^1)} - \frac{d^1}{(d^2 - d^1)}$$

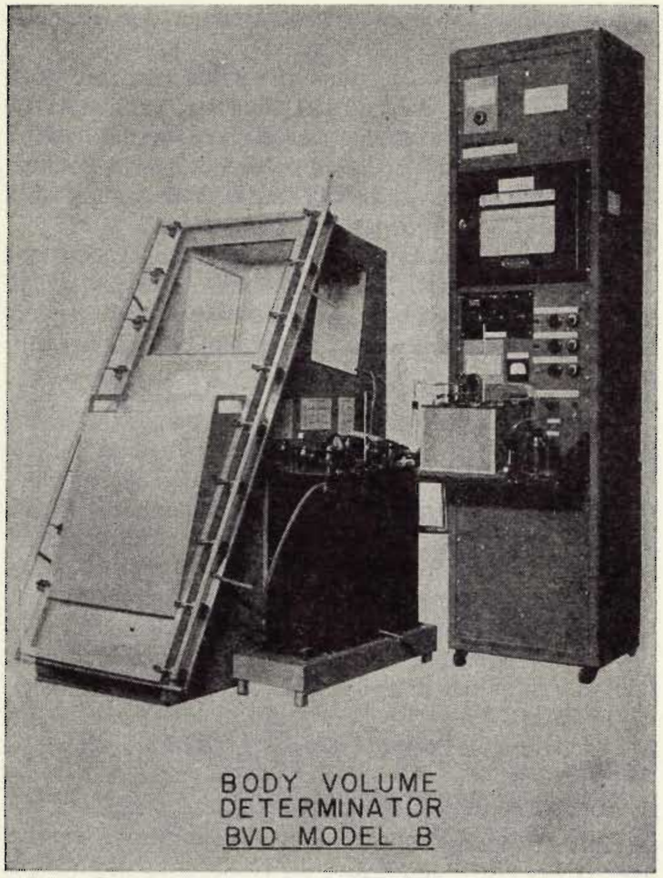
if M^2 is desired:

$$M^2 = \frac{1}{D} \cdot \frac{d^1 \times d^2}{(d^1 - d^2)} - \frac{d^2}{(d^1 - d^2)}$$

The volume which is needed for calculating body density $\left(D = \frac{\text{Mass}}{\text{Volume}}\right)$ can be determined by underwater weighing when corrections for residual air in lungs and GI tract are applied. This method was well described by Behnke *et al.* (1942, 1961), Brožek *et al.* (1949), Goldman and Buskirk (1961).

Underwater weighing method is rather difficult to use on children, older subjects or cardiac patients. In order to determine their body composition, the gas-dilution method was developed.

This method is based on a principle in which a suitable solute (helium) is used for indirect determination of the solvent volume (air). Two chambers are needed: a large closed chamber for the subject and another to contain the helium. The helium is mixed under atmospheric pressure with the air of the chamber where the



subject is located. Siri (1956) described well the method in his work for the United States Atomic Energy Commission as well as the calculation of body volume using helium dilution methods. Figure 1 portrays the apparatus for determination of body volume by gas dilution method.

Estimation of Muscle Mass: The largest fraction of fat-free mass is the muscle tissue. Creatinine is thought as a product of the muscle tissue. Conveniently, the output of this substance is usually expressed as the creatinine coefficient (C.C.) which is the amount of creatinine in milligrams excreted in 24 hours divided by the body weight in kilograms. However, the C.C. gives only a relative estimate of the fat-free mass because of the total body weight used in the determination of the coefficient. This weight does not consist of the muscle mass only but contains certain amount of fat and bone as well.

However, the creatinine excretion expressed in g/24 hours does give a reasonable estimate of the muscle mass and it is preferred by many investigators. Creatinine excretion is practically the same between both sexes up to the age of ten. From that age on the boys show greater creatinine excretion as compared to girls. This sex difference persists throughout adulthood. Thus, the differences in muscle mass are well exemplified by the creatinine excretion. Monographs of Hunter (1928) and Beard (1943) present a full treatment of the problems involved.

The Minnesota team (Brožek, Grande, Anderson, Keys) suggest a more refined approach to the problem of determination of so called "active protoplasmic tissue." This compartment, consisting of all the cells in the body without any fat, connective tissue, etc. was designated as "cells."

To estimate "cells" in the human body a four component system has to be considered, namely:

$$M = B + C + F + E$$
$$C = M - B - F - E$$

where M = total body mass, B = bone mineral, F = total body fat and E = extracellular fluid.

Because cells do contain water, the compartment can be calculated according to the following equation:

$$C = \frac{A - E}{0.733}$$

where A = total body water, E = extracellular water and 0.733 is the fraction of water in "cells" (Grande *et al.*, 1958).

Another method of estimating "active protoplasmic tissue" or the "cell mass" is by oxygen consumption. At a given time the basal oxygen consumption is equal to the amount of oxygen consumed by all the cells in the body.

It has been demonstrated by Grande *et al.* (1958) that the basal metabolic rate per kg of "cell mass" is 1.6 Cal. as compared to the basal metabolic rate per kg of fat-free mass which amounts to 1.3 Cal. These values apply to "reference" standard man as defined by Keys and Brožek (1953). The changeable metabolic rates of skeletal muscles, heart, kidneys, liver and possibly brain under different physiological conditions and in different individuals infer that the basal metabolic rate expressed in calories per kg of either "cell mass" or fat-free mass should not be considered as constant values.

Total Body Counter: The natural gamma radioactive potassium — K^{40} — in the human body can be counted in few minutes by the total body counter. Potassium is an important cation found mainly inside the cells. Therefore, the estimate of the potassium provides information about the amount of the body mass minus fat, water and bone mineral.

A large, well shielded cubicle is needed for studies of potassium — K^{40}. This counter produced commercially is somewhat prohibitive in price but well suited and in financial reach of multi-disciplinary projects. Further, the total body counter provides the opportunity for research on infants and children where administration of isotopic material such as K^{42} limits the scope of investigators. Allen, *et al.*, Anderson, *et al.* and Forbes *et al.* (1961) provided a description of the total body counter and data on K^{40} as an estimator of "cell mass."

Measurements of Total Body Water: Water constitutes about two-thirds of the total mass in mammals. Water balance is well controlled in the body by a complex mechanism. The total body water is contained in two fluid compartments. The intracellular is that of the cells and the extracellular fluid is that outside of the cells.

An ideal test substance to measure total body water is one which quickly dissolves in the body water, penetrates all the water in the body, is not absorbed by other body constituents and is easily measured when eliminated from the body.

Antipyrine, deuterium oxide and tritium are the substances of choice for determination of total body water. Soberman (1949) and Friis-Hansen (1951) provided ample information about the usage of antipyrine while Schloerb (1950) and Solomon *et al.* (1950) dealt in a detail with mass spectrometer for measuring deuterium concentration. Siri (1956) and Edelman (1961) presented a full treatment of using tritium and how to detect its beta particles either with ionization chamber with sensitive current-measuring device (electrometer) or with liquid scintillation counters. Currently, the counters seem to be the choice for research.

Simultaneous Multi-Parameter Method: In the past, extracellular fluid was determined separately by inulin, mannitol, sucrose and by a variety of ions such as thiocyanate, sulphate, bromide, thiosulphate, sodium and chloride. The intracellular fluid was obtained from the measurements of total body water minus that of the extracellular fluid.

Moore (1963) and his group at Harvard Laboratories developed a simultaneous multi-parameter method which facilitates determination of body compartments within 48 hours. Isotope dilution techniques are used as follows: the red cell volume is determined with Cr^{51}, plasma volume with T-1824, total body water with D_2O, extracellular volume with Br^{82}, total exchangeable sodium with Na^{24}, and total exchangeable potassium with K^{42}.

The simultaneous multi-parameter method is presented well by James *et al.* (1954) and McMurrey *et al.* (1958). Great number of sensitive counters for isotope dilution method on the market provide the research of body composition with more profound methods to find additional information of parameters formerly unknown.

In order to exemplify the practical application of the method, an example is included. The exchangeable potassium provides information about fat-free solids. Fat-free solids together with total body water constitute fat-free mass. Fat can be determined conveniently by subtracting fat-free mass from the total body weight.

Estimation of Skeletal Weight: The estimation of the different compartments of the body has its weakest point in the non-existing data of the skeletal weight as a part of the fat-free body. Trotter and Peterson (1955) reported data on seven skeletons with varying ash weights. Because bone mineral forms a reasonably constant part of dry defatted bone weight, Keys and Brožek (1953), in developing the equations for estimating the amount of fat in the body on the basis of body density, assumed that mineral content in the body accounts for 6% of the body weight. Bone density, being the highest of all body components, (fat = .9007, cells = 1.057, extracellular fluid = 1.002 and bone mineral =3.00) is subject to individual variations. Therefore, these variations will effect the determination of the total body density. This value, in turn, will produce an erroneous estimate of the total body fat.

More recent investigations of Baker and Newman (1957) and Baker *et al.* (1959) indicate that about 4% of the body weight should be assigned to the skeletal weight. This estimate is based on the studies of defatted dry skeletal weight and bone mineral of young adult whites.

Present methods of estimating skeletal weight are based on X-ray techniques. The predictions of skeletal weight which were obtained mostly on cadavers need to be corrected before any formulae can be applied to living subjects.

Summary: A short review of methods for studying body composition has been presented. Physical anthropologists have a great interest in this field. They can contribute to many problems in growth studies, nutritional disorders or in the field work through anthropometry which involves simple estimates of subcutaneous tissue, musculature, linear dimensions, areas and volumes.

The more profound biophysical and biochemical methods used in determinations of body compartments imply laboratory equipment and a wide background in biological sciences of any physical anthropologist who wants to understand the complex problems associated with body composition.

The many interests, such as growth, aging, sex differences, racial differences, effects of nutrition, physical activity and environment plus the relationship of physique to non-infectious diseases, make the field of modern physical anthropology a challenging and rewarding scientific discipline.

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