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ANATOMY WITHOUT DISSECTION: EVALUATION OF BODY COMPOSITION IN VIVO*

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The problem of body composition, with special reference to body fat, has been examined in detail (1) with special attention to the logic and the arithmetics of the formulae used in the calculation of body compartments. It is the purpose of this paper to present, in a succint way, the principal ideas and methods. While the biochemical and biophysical approaches are more elegant and, indeed, more fundamental, it is the anthropometric analysis which is particularly suitable for much of the research in the field and in the clinic and deserves, consequently, particular attention. In laboratory investigations, where neither a shortage of time nor lack of equipment is an obstacle to a comprehensive study, the combination of all three approaches yields the fullest information.

1. *Introduction*

In the science of human work and in other contexts in which a valid reference point is needed for energy metabolism at rest and at work as well as for a variety of other metabolic processes and physiological functions, the separation of body fat and the fat-free portion of the body is the first and fundamental step. For many purposes it is desirable to break down the fat-free body mass into its components. These may be variously defined.

McCance and Widdowson (2) measured body weight, total body water (by urea dilution) and the extracellular fluid (by thiocyanate

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dilution). They estimated the cell mass (1.4925 × intracellular fluid) and the bone mineral (0.07 of the fat-free body weight). Body fat was the remainder of gross body weight, after one has accounted for the weight of extra-cellular fluid, cell mass, and bone minerals.

In their biochemical analysis Keys and Brožek (1) started with the theoretical division of the total mass of the body into total water, cell solids, bone minerals, and body fat. Hamwi and Urbach (3) differentiated the same four basic body compartments. In the actual computations only the values of total body water and extracellular fluid are used in these systems.

Siri (4) has divided the fat-free fraction into body water and the lean body solids. The latter, in turn, is a complex concept representing a mixture of dry protein plus minerals. In Siri's equation for the estimation of body fat, only body mass, volume, and the mass of the total body water are entered but the assumed density of the lean body solids affects the values of the coefficients by which these variables are multiplied.

The »best« way in which the fat-free body is divided depends on the investigator's purposes and our ability to measure or estimate independently the individual components.

2. *Biochemical dilution methods*

Several biochemical approaches to the study of body composition have been developed. Some of these deal only with *changes* (such as nitrogen or calcium balance studies) while others yield estimates of absolute *amounts* of certain body tissues. As far as body fat in concerned, direct methods based on the dilution of fat – soluble indicators (cyclopropane) were used only in animal studies (5). The excretion of creatinine has been repeatedly considered as a possible measure of muscle mass but the validity of the technique remains questionable. Early attempts to estimate body fat were based on measuring the amount of nitrogen washed out by breathing oxygen for several hours and partitioning it between the fluid and the fat phase (compartment) (6). Recently, the possibility of predicting the »lean body mass« from basal oxygen consumption has been explored (7). In man, the measurement of total body water and of some of its fractions is the most important tool. Only this method will be considered here.

Water is the largest single component of the body and its determination is of interest for its own sake. The possibility of determining its fractions, especially the extracellular (and its complement, the intracellular) fluid, increases the theoretical interest and the practical importance of body water determinations, providing means for a quantitative characterization of the state of hydration. In the present context the high negative correlation between total body water and body fat, and the possibility of estimating the latter from the former is particularly relevant.

The analysis developed elsewhere in detail (1) involved the separation of the total mass of the body (M) into fat (F), total water (A), cell solids (S), and bone mineral (B).

$$M = F + A + S + B \tag{1}$$

Two other symbols are needed – E for extracellular fluid and I for intracellular fluid ($I = A - E$) – for defining the components S and B. Cell solids, S, were computed as the difference between the cell mass (C, estimated from I which represents about 70% of the cell mass $I = 0{,}7\ C$) and the intracellular fluid, $S = C - I$. On substitution,

$$S = 0.429\ (A - E) \tag{2}$$

The bone mineral was expressed in terms of the cell solids ($B = 0.313\ S$), yielding

$$B = 0.134\ (A - E) \tag{3}$$

With these values and $M = 1$, the total body fat is calculated according to the formula $F = 1 - A - S - B$, yielding

$$F = 1 - A - 0.563\ (A - E), \text{ or, in final form,} \tag{4}$$

$$F = 1 - 1.563\ A + 0.563\ E \tag{5}$$

In a normally hydrated body, with $E = 0.16\ M$, the last equation is reduced to

$$F = 1.090 - 1.563\ A \tag{6}$$

A variety of substances has been examined as potential indicators of total body water (A), taking into account such factors as penetration into the tissues and uniformity of distribution, the rate of elimination or destruction, toxicity, and ease and precision of measurement. For application to man antipyrine (8), urea (9), and deuterium (10) appear, relatively, as the most promising solutes for estimating body water on the dilution principle. The variability of repeated determinations made in the same individuals has been studied most systematically with antipyrine and has been found disturbingly large for application to individuals, with replicate standard deviations from about 3 to 5 per cent of the mean water content of the body. In terms of absolute amounts, both antipyrine and urea give somewhat smaller values than heavy water.

While the fluid space obtained by inulin dilution represents more nearly the true amount of »extracellular« fluid, the thiocyanate space is larger (about 16 and 23 per cent of body weight, respectively, in normal young men). However, the thiocyanate method is technically simpler and the »true« extracellular fluid space may be estimated as a fraction of the thiocyanate space (T).

With E = 0.7 T we obtain the equation

$$F = 1 - 1.563\ A + 0.394\ T \qquad (7)$$

In the estimation of body fat from total body water the biological assumptions, which are only approximately correct for individual subjects, concern the constancy of hydration of the cells and of the relationship between cell mass and bone mineral. The uncertainty associated with the coefficients in equation (2) and (3) was estimated (1) as 0.429 ± 0.050 and 0.134 ± 0.029. In the equation (4) we have the coefficient 0.563 ± 0.058:

$$F = 1 - A - (0.563 \pm 0.058)\ (A - E) \qquad (8)$$

This is the uncertainty due to the individual differences in the »constants«. To this source of variation must be added variability associated with the methods for the determination of total body water and the extracellular fluid, which is not negligible.

3. *Biophysical methods*

There is no distinct demarcation line between the biochemical and the biophysical methods. In fact, the latter depend for their validation on chemical analyses and the simultaneous determination of the water content of the body, especially of the extracellular fraction, increases the precision of the densitometric analysis. Nevertheless, the distinction between the biophysical and biochemical methods may be useful, at least for the purposes of presentation.

In the system consisting of two components of known densities (d_1, d_2) the densitometric analysis enables one to determine the proportional masses of the components (C_1 and C_2; with the total mass M = 1, $C_2 = 1 - C_1$).

$$C_1 = \frac{1}{D} \cdot \frac{d_2\, d_1}{d_2 - d_1} - \frac{d_1}{d_2 - d_1} \qquad (9)$$

Rathbun and Pace (11) have defined the first component as body fat, with $d_F = 0.918$, the second component as the fat-free (»lean«) body mass, with $d_L = 1.1$. With these values equation (9) becomes

$$F = \frac{5.548}{D} - 5.044 \qquad (10)$$

The criticism of this formula and the underlying concepts and constants has been offered elsewhere (1). As an alternative, analysis based on new data on the density of the human fat and on experimental studies of induced obesity was developed in the Laboratory of Physiological Hygiene.

In this system the two components into which the body is separated, densitometrically, is the mass of standard density ($d_s = 1.0629$ gm./cc., defined as the mean density of young men of »normal« weight for height and age) and the »gain« ($d_G = 0.948$ gm./cc., representing the mean density of tissues gained by positive caloric balance over a period of 6 months [12]). Using these values in equation (9)

$$G = \frac{8.753}{D} - 8.235 \qquad (11)$$

It was shown by a combined biochemical and densitometric analysis that the »gain« consisted of about 14% extracellular fluid, 24% cells, and 62% fat ($F = 0.62\ G$).

Most frequently the *relative* fatness of an individual, the deviation from the standard ($\triangle F$) is of interest. Having determined the body density, we calculate $\triangle F$ directly as

$$\triangle F = \frac{5.427}{D} - 5.106 \qquad (12)$$

The total amount of body fat (F) can be estimated having made an assumption, consistent with the known facts, that in the standard reference body ($d_s = 1.0629$) fat represents 14% of the weight. In a given individual the proportional mass of standard density is $(1 - G)$. Thus the total fat is

$$F = 0.14\ (1 - G) + \triangle F \qquad (13)$$

With $\triangle F = 0.62\ G$, using equation (11) for defining G, we obtain

$$F = \frac{4.201}{D} - 3.813 \qquad (14)$$

F represents the proportional mass of fat (ether extract, not the anatomist's adipose tissue) in the body.

One of the assumptions on which rests the validity of this estimate is that the hydration of the body is normal. In the standard reference man the extracellular fluid accounts for 16 per cent of the body weight (fat for 14%, bone mineral 6%, »cellular matter« for 64%). Increased amount of intracellular fluid, with its low density (about 1.002 gm./cc. as compared to 0.9007 for fat, 3.0 for bone mineral, and 1.057 for »cellular matter«), simulates higher fat content.

When measurements of the extracellular fluid (E) have been made, it is possible to take into account the deviation in hydration in the calculation of the »excess fat« ($\triangle F$) and the total fat (F) Thus we obtain

$$\triangle F = \frac{5.359}{D} - 0.366\ E - 4.982 \qquad (15)$$

$$F = \frac{4.149}{D} - 0.283\ E - 3.717 \qquad (16)$$

As to the methods, body volume (V) needed for the calculation of body density can be obtained, on the basis of the Archimedes principle, by weighing the subject in air and under water. The formula is

$$V = \frac{M_A - (M'_W + V_R D_W)}{D_W} \qquad (17)$$

where M_A = weight in air, M'_W = apparent weight in water, D_W = = density of the water in the tank, and V_R = volume of air remaining in the lungs and the respiratory passages at the time of submersion (determined in the Laboratory of Physiological Hygiene) by the nitrogen dilution method (13).

Body density, the ratio of mass and volume ($D = M_A/V$), can be readily computed on a calculating machine using the formula

$$D = \frac{M_A D_W}{M_A - M'_W - V_R D_W} \qquad (18)$$

The extracellular fluid, as indicated earlier, can be obtained as a fraction (0.7) of the fluid space in which thiocyanate distributes itself.

4. *Anthropometric methods*

In the past physical anthropologists have little concerned themselves with the problem of body composition, even though it has very important implications for anthropology (14). At the same time, anthropometric methods can contribute significantly to a wide utilization in field research of the basic concepts and of information on body composition gathered in laboratory investigations. At present these matters represent an active area of research which shows both the positive and the negative characteristics of pioneering scientific ventures, with duplication of research, lack of standardization of methods and inadequate systematization of the investigative efforts. It is hardly surprising that the promises and potential usefulness are larger than solid and permanent accomplishment.

The classical anthropological measurements, largely focussed on osteometry, have been of very limited usefulness for metabolic, and, more specifically, for nutritional research. The crucial problem of body build has been approached principally through a myriad of indexes, mostly poorly constructed. Unfortunately, the majority of those who were dissatisfied with the »classical« anthropometric methods and the numerology of indices have pretty much given up the idea of rigorous quantification of body build and followed the path of »intuitive« (somatoscopic) classification. In this field Sheldon's (15) influence has been outstanding. Unfortunately, the »primary components« of human physique in Sheldon's system of somatotyping – endomorphy, mesomorphy, ectomorphy –, derived from inspectional analysis of photographs of nude subjects, have no well defined relation to the anatomical or histochemical concepts of body composition.

Photographs, taken in a standard manner and with appropriate posture of the subject, are a potentially useful tool for the description of man's physique in terms of biologically well defined components. However, at present we lack a system for inspectional ratings of these components and for making appropriate measurements which can be interpreted in terms of body composition. Some recent studies, not specifically directed to this problem (16, 17) support the idea that such a system can be developed.

The principal new ideas, expressed in gross outlines already by Matiegka (18), included (1) measurement of structurally »pure« aspects of the human organism, and (2) estimation, from these linear dimensions (and body weight), of the masses of principal body tissues. Gross body weight, the bideltoid diameter (including a bony, muscular and adipose component) or the chest circumference represent – in terms of tissue morphology – complex measurements which can not be properly utilized for a componental analysis of body build.

By contrast, a fold of skin plus the subcutaneous tissue (where the latter accounts for the largest part of the variability of the measurements made in different parts of the body and in individuals of different degree of fatness), the bicristal diameter, and the cross-sectional area of the thigh (corrected for the overlaying fat and, preferably, also for the bone) represent dimensions constituted by relatively homogeneous tissue – »fat« (adipose tissue), bone, and muscle.

For a variety of purposes, including some studies of growth and nutriture, a quantitative characterization of an individual in terms of these measurements (preferably interpreted against the background of normative data, based on clearly defined populations) is sufficient. What is needed are adequate instruments, particularly tapes and skinfold calipers with constant pressures, and the standardization of the procedures which will allow a cumulation and comparisons of data obtained by different investigators. These problems are under active consideration, especially in the Unites States (Committee on Nutritional Anthropometry, Food and Nutrition Board, National Research Council) and in England.

In addition to external measurements – which, alone, have only limited value – the roentenographic technique has been used for quantitative tissue differentiation. The history of the application of this approach in the English speaking countries has been presented, together with the results of extensive original investigations, by Reynolds (19, p. 10). The principal idea is that in the limbs a »soft-tissue roentgenogram« allows a differentiation of the superficial (skin plus subcutaneous adipose tissue), muscular, and bony layer and in some other parts of the body it makes possible the measurement of the subcutaneous fat. The results obtained up-to-date indicate that roentgenographic (roentgenogrammetric) studies may serve as a valuable tool in research on human growth. While the technique has its inherent limitations, technical as well as economical, its extension to studies relating body composition to different aspects of metabolism is feasible. Valuable methodological information can be obtained by a simultaneous application of the roentgenogrammetric analysis and external measurements on the one hand, and of the biochemical and biophysical methods on the other hand.

Matiegka conceived the idea of going beyond the one or two-dimensional measures (such as skinfolds or body surface) and of estimating, from prediction equations, the mass of the principal tissues. His important article, published in a journal with limited circulation, has all but been lost out of sight. Consequently, a somewhat more detailed exposition of his approach appears warranted. The formulae for calculating the mass of 3 anatomical components of body weight, estimated from anthropometric data, are indicated in Table 1.

Table 1

Matiegka's formulae for calculating the weight, in grams, of the skeleton (O.0552), skin plus subcutaneous fat (D, derma) muscles (M):

$$O = o^2 \times L \times k_1 \quad (19)$$

$$D = d \times S \times k_2 \quad (20)$$

$$M = r^2 \times L \times k_3 \quad (21)$$

where $k_1 = 1.2,\ k_2 = 0.13,\ \text{and}\ k_3 = 6.5$

L = stature, in cm, S = body surface, in cm^2.

$o = \frac{o_1 + o_2 + o_3 + o_4}{4}$ with o_1 to o_4 representing the maximum transverse diameters of hummeral and femoral condyles, wrist and ankle, in cm.

$d = 1/2\ \frac{d_1 + d_2 \ldots . + d_6}{6}$, with d_1 to d_6 referring to the thickness of the skinfold on the upper arm, above biceps; the forearm, plantar side at maximum breadth; thigh, above quadriceps muscle, half-way between inguinal fold and the knee; calf of the leg; thorax, on costal margin, half-way between the mipples and the umbilicus; and abdomen, half-way between the navel and the anterior superior iliac spine.

$r = \frac{r_1 + r_2 + r_3 + r_4}{4}$, with r_1 to r_4 representing the radii calculated from the circumferences of the arm, flexed, measured above the belly of the biceps; forearm, maximum; thigh, half-way between the trochanter and the lateral epicondyle; and leg, maximum circumference of the calf. The values are corrected for the thickness of the subcutaneous tissue plus the skin.

The estimation equations involve chiefly measurements made on the extremities. Only the skinfolds, measured with a sliding caliper under minimal pressure, included also 2 measurements of subcutaneous fat on the trunk (chest and abdomen). Body weight and stature are involved in the calculation of body surface.

Measurements of the circumference of the wrist have been introduced long ago by physicians of some Austrian insurance companies, with the aim to characterize the robusticity of skeletal structure. It is probable that the extremities provide a good basis for estimating the total mass of the skeleton but we are not aware of data providing an empirical verification of this thesis. An a priori grounds, the inclusion of a measurement characterizing the size of the pelvic girdle (preferably the bicristal diameter) appears to be a useful addition to the measurements of the extremities. We trod on a still more uncertain ground when we consider the relationship between the soft tissues of extremities and of the body as a whole. It is known that in the process of aging the subcutaneous adipose tissue shows larger increments in the trunk than in the legs and the arms (20, 21).

While various aspects of Matiegka's system are open to criticism, the principal weakness is the uncertainty concerning the coefficients (k) in the equations, which represent intelligent guesses – no less, no more. They were derived synthetically, principally on the basis of fairly meager data in the literature, not analytically by actual comparison of anthropometric measurements and the tissue masses separated on dissection. This could be done most readily for a component that eludes precise estimation by biochemical methods (in man *in vivo)* and importantly affects the precision of the densitometric analysis – the skeletal structure. Such data could be refined and supplemented, in special investigations, by the X-ray analysis of bone mineralization (22). The skeletal weight appears to represent a useful reference point for the comparison of relative amounts of other tissues in the body.

Matiegka's analysis has been made in terms of the muscle mass, the skeleton and the subcutaneous adipose tissue (plus the skin). It fails, as must all anthropometric methods which operate with gross body weight, in patients with abnormal hydration (edema). Also, it would appear desirable to relate the anthropometric analysis more closely to the biochemical and densitometric analysis; for one, it seems that the total body fat rather than the subcutaneous adipose tissue should be considered. However, systematic data, obtained within the frame of anatomical composition of the body and based on valid estimates of the amount of the tissues, with norms taking into account such factors as age and sex, would go far toward an effective characterization of the individual in terms of bony mass (percentiles based on absolute values) and the relative development of muscles and fat (in reference to the skeleton).

In order to tie together the anthropometric and densitometric analysis (23), the coefficients of correlation were computed between 5 skinfolds and the relative body weight (actual weight as percentage of the tabular standard) on the one hand and the specific gravity, used as an index of total body fat (11), on the other hand. The relationships were expressed, for practical purposes, in a form of equations for predicting specific gravity of the body on the basis of single anthropometric criteria of »fatness«. In addition, a prediction equation based on an optimal combination of the prediction variables was obtained. For young men, the predicted specific gravity ($\hat{Y}$) is obtained according to the equation:

$$\hat{Y} = 1.1017 - 0.000282\,A - 0.000736\,C - 0.00883\,U;$$

for middle-aged men (ages 45–55 years).

$$\hat{Y} = 1.0967 - 0.000393\,C - 0.000315\,B - 0.000598\,U - 0.000170\,P$$

where A, B, C, U are the skinfolds measured at the abdomen, back, chest, and upper arm, and P is the relative weight. The skinfolds were measured with a high-tension caliper (above 30 gm/mm^2). The values of the specific gravities of the body refer to water temperature in the tank of about 36^0 C (density of water, $D_W = 0.994$) and can be converted into density values $D_B =$ sp. gr. $\times D_W$).

The study has been repeated (Laboratory of Physiological Hygiene, to be published), making individual determinations of the residual air rather than applying an average correction, as has been done in the initial study. In spite of these limitations, the approach seems to me useful for physiological investigations, in addition to field work for which it was designed (24).

5. *Some applications*

The range of application of the methods for the study of body composition *in vivo* is large. Elsewhere (1) we have reviewed data, reported in the literature and those obtained in the Laboratory of Physiological Hygiene, which dealt with changes in body composition during aging, sex differences, body build, analysis of weight changes, basal metabolism and basal cardiac output.

Historically, Kohlrausch (25) used densitometry as a tool for the study of body composition in connection with the effects of exercise. This remains a fruitful area of research, as physical exercise and occupational work are the most widespread type, in addition to dietary intake, of physiological experimentation on man. It has been shown (26) that physical activity, in »normal« individuals, is associated with somewhat lower fat content and definitely higher fat-free body weight.

In the Laboratory of Physiological Hygiene we have been interested since 1944 in body composition as means for a quantitative evaluation of an important aspect of nutritional status (nutriture) (27). The applications in nutritional research are perhaps potentially the most numerous.

The problems of growth and aging, both in men and animals, represent another area which is wide open to fresh examination in terms of body composition. In the Laboratory of Physiological Hygiene we have been concerned with one segment of the life cycle, the changes taking place during adult life (maturity) (20, 21). External body dimensions and gross weight are inadequate criteria of growth, and maintenance of body weight in the adult does not prove the absence of shifts in the relative amount of different body tissues.

Thus middle-aged men, matched for height and weight with young men, showed a larger amount of body fat (with a reduced fat-free body weight). In experimental animals the possibility of a progressive protein depletion in spite of body weight maintenance was noted by Anderson and Nasset (28, p. 634).

Data on body composition, as new means for the characterization of body build, may serve as a reference point for psychological, physiological and pathophysiological studies (29). There are important unsolved problems concerned with leanness-fatness in reference to the development of the so-called degenerative diseases, especially arteriosclerosis.

One may examine the effects of biochemical, e. g. hormonal factors, on body composition (30) and there is the pharmacological problem of regulating the dosage of certain drugs in the light of the data on body composition rather than expressing it in reference to body weight of which 30 percent and more may be fat. The higher affinity of certain substances for fat may have some implications for industrial toxicology.

While the methodological contributions to the study of body composition have come principally from biochemistry and biophysics, radiology and physical anthropology, the procedures and the data are of interest for a surprisingly large number of disciplines in the broad field of human and animal biology, theoretical and applied, including internal medicine and surgery. The present brief survey has been limited principally to recent methodological developments and to some applications at the Laboratory of Physiological Hygiene of the indirect methods for the study of body composition.

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Sadržaj

ANATOMIJA BEZ DISEKCIJE: ODREĐIVANJE SASTAVA TIJELA IN VIVO

Problem sastava tijela je jedno od najinteresantnijih pitanja suvremene biologije čovjeka. Metodološku bazu za ispitivanje sastava tijela *in vivo* stvorile su biokemija, biofizika, radiologija i fizikalna antropologija. Mogućnosti primjene tih metoda su široke te obuhvaćaju cijeli niz teorijskih i primijenjenih disciplina.

U ovom kratkom pregledu autor se ograničio uglavnom na metode izrađene u Laboratoriju za fiziološku higijenu na osnovi teorijske analize i novih podataka o gustoći masnoće i tkiva dobivenog pri debljanju.

Jednadžba za određivanje totalne količine masti (F) u tijelu biokemijskom metodom glasi:

$$F = 1 + 0{,}563\,E - 1{,}563\,A,$$

gdje je A = totalna količina vode, E = ekstracelularna tekućina. Vrijednost A može se odrediti razređivanjem različitih supstancija (antipirin, urea, deuterium). E se može dobiti kao funkcija prostora, u kojem se razređuje tiocijanat (E = 0.7 T). Onda se F može odrediti kao

$$F = 1 + 0{,}394\,T + 1{,}563\,A$$

U tijelu s normalnom hidratacijom (E = 16% tjelesne težine; T = 23% tjelesne težine) jednadžba za izračunavanje totalne količine masti reducira se na

$$F = 1{,}090 - 1{,}563\,A.$$

Na bazi densitometrijske metode možemo odrediti količinu masti ($\triangle F$), po kojoj se pojedinac razlikuje od »standardnog čovjeka« (kojeg gustoća D iznosi 1,0629), kao i totalnu količinu masti (F):

$$\triangle F = \frac{5{,}427}{D} - 5{,}106$$

$$F = \frac{4{,}201}{D} - 3{,}813$$

Metoda je točnija, uzmemo li u obzir ne samo gustoću tijela (D), nego i količinu ekstracelularne tekućine (E).

Rentgenografska analiza pomoću rentgenograma mekih tkiva omogućuje mjerenje debljine površnog (adipoznog), mišićnog i koštanog sloja ekstremiteta. Razvoj adipoznog tkiva, mišića i kostiju može se karakterizirati i na bazi direktnih antropometrijskih mjerenja strukturno homogenih dimenzija tijela.

Češki antropolog Matiegka je 1921. god. nabacio ideju određivanja mase glavnih tkiva na bazi antropometrijskih podataka, ali njegove jednadžbe nisu bile provjerene anatomski.

Želeći povezati antropometrijsku analizu s densitometrijskom metodom ispitali smo korelacije između antropoloških mjera debljine, naročito nabora kože, i dobili jednadžbe za izračunavanje specifične težine na bazi optimalne kombinacije antropometrijskih mjerenja. Specifična težina bila je mjerena pri temperaturi vode od oko 36° C i može se lako izraziti kao gustoća (gustoća = spec. tež. × gustoća vode, gdje je gustoća vode = 0,994).

Primjena novih metoda za studij sastava tijela kod živog čovjeka, koje su izrađene u Laboratoriju za fiziološku higijenu univerziteta u Minnesoti, otvorila je novi put istraživanjima efekata fizičkog rada, stanja prehrane, rasta i starenja, hormonalnih faktora i korelacije između građe tijela, metabolizma i fizioloških funkcija.

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