THE EARLY NINETEENTH CENTURY witnessed the first concerted application of chemical techniques to the investigation of biologic materials. Milk was chemically analyzed, von Liebig discovered the chemical contrast between potassium-rich cells and sodium-rich tissue fluids, and Carl Schmidt analyzed blood serum in great detail. Soon these methods were applied to the study of the entire human body.

The advent of isotopic dilution techniques in the 1930's and 1940's brought about a renewed interest in body composition. More recently these and other techniques have been used in an attempt to study the nutritional aspects of body composition. It is the purpose of this report to present the various methods now in use and to discuss the virtues and limitations of each.

DIRECT CHEMICAL ANALYSIS

Whole Body

During the past century a number of human carcasses have been analyzed for water, fat, nitrogen, sodium, potassium, chloride, calcium, magnesium, and phosphorus. These include the fetus, newborn, and adult. The few analyses done on children have included subjects suffering from conditions known to profoundly affect water and electrolyte metabolism.

Data for total body content in the newborn and adult are presented in Table I, both on a fresh-weight and a fat-free fresh-weight basis. The latter basis for expressing values avoids discrepancies that arise because of alterations in fat content. It is evident that significant changes in body composition occur during growth. Water, sodium, and chloride contents decline, while contents of nitrogen, calcium, potassium, magnesium and phosphorus all increase. In these data, body fat content is not strikingly different in the two age groups. As will be discussed later, measurements on living subjects reveal an increasing adiposity in later adult life.

The extensive observations of Widdowson and her co-workers have shown that growth changes occur in body composition of other mammalian species, changes that are comparable in magnitude and direction to those of the human. These species include the mouse, rat, cat, guinea pig, rabbit, and pig. It is entirely probable, therefore, that the trend of changes in body composition depicted in Table I represents a phenomenon common to all mammalian protoplasm.

In considering the data of Table I, it is evident that some variation is present, even when the values are calculated on a fat-free basis. Sources of variation include losses of electrolyte when tissue specimens are ashed, technical difficulties in analyzing
TABLE I

**Total Body Composition**

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Water (H₂O)</th>
<th>Fat</th>
<th>Nitrogen</th>
<th>Na</th>
<th>Cl</th>
<th>K</th>
<th>Ca</th>
<th>P</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Per cent</td>
<td>mg/kg</td>
<td>gm/kg</td>
<td>mg/kg</td>
<td>gm/kg</td>
<td>References</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Newborns (6) (av 3,350 gm) | 70 | 12 | 1.97 | 76 | 50 | 40 | 7.2 | 4.5 | 0.17 | Camerer & Söldner
| | (69-73) (10-16) (1.8-2.4) | (67-81) (45-54) (56-68) | (5-9.5) (3.1-5.3) (0.1-2.2) | | | | | | |
| Newborns (6) (av 3,350 gm) | 69 | 16 | 1.90 | 82 | 22 | 44 | 8.0 | 4.7 | 0.32 | Widdowson
| | (11-89) (1.7-3.4) | (77-87) (59-71) | (7.4-9.9) (4.3-5.5) (0.1-2.4) | | | | | | |
| Adults (av 66) | 61 | 44 | 3.16 | 58 | 38 | 55 | 18 | 9.1 | 0.38 | Older German literature
| | (58-68) | | | | | | | | |
| Adult female | 56 | 24 | 2.30 | 71 | 45 | 19 | 9.9 | 0.33 | Subject "IL" Widdowson et al.
| | (av 3,560 gm) | | | | | | | | |
| Adult male | 68 | 12 | 2.31 | | | | | | |
| Adult male | 55 | 18 | 2.98 | 68 | 56 | 54 | 19 | 9.2 | \{ R. M. Forbes et al. \} \{ G. B. Forbes and Lewis \}
| | (av 3,350 gm) | | | | | | | | |
| Adult male | 54 | 27 | 2.76 | 37 | 40 | 40 | 16 | 8.2 | 0.35 |
| Adult male | 71 | 4 | 3.16 | | | | | | |
| Averages | 62 | 17 | 2.70 | 66 | 58 | 55 | 18 | 9.1 | 0.38 |

* Variations expressed either as range or standard deviation.
† Widdowson's series included one large subject (3,357 gm) containing 15.5% fat by analysis. The distribution of values for fat content is thus skewed. This subject also contained a large amount of sodium (108 meq/kg fat-free weight), though other constituents were normal. Average values for the remaining five subjects are fat 13.6% (range 11-15), and sodium 96.3 ± 1.9 meq/kg.

The lower values for Na, K, Ca, P, and Mg in Camerer and Söldner's study of newborn infants in comparison to Widdowson's results. For example, the former group of subjects weighed less (2,480-3,350 gm) than the latter (3,050-4,375 gm). The low value for Na reported in the adult by Shohl and the high value reported by Widdowson et al. are unexplained; the former differs so much from those reported by other workers that analytic error seems likely.

Perhaps the most serious source of error lies in the fact that some, or perhaps all, of the subjects are not representative of the normal population. The obvious fact that death occurred raises the distinct possibility of chemical derangement.

**Individual Tissues**

A number of individual tissues have also been studied. During growth the concentrations of water, sodium, and chloride in muscle and brain decline while that of potassium increases. Of interest is the fact that this trend is reversed, though to a very slight degree, in ageing rat muscle. In experimental malnutrition, the infantile type of chemical pattern in muscle tends to persist. Bone differs from most soft tissues in that sodium content increases during...
growth, as does the content of calcium, phosphorus, and magnesium, though water content does diminish. The value of biopsy specimens in assessing nutritional status is somewhat limited except in instances of severe malnutrition, or where definite metabolic abnormalities exist. Biopsy analysis provides information on the tissue concentration, not on total body content.

INDIRECT MEASUREMENTS OF WATER AND ELECTROLYTES

Obviously chemical analysis must be limited to biopsy specimens in living subjects. In recent years, a number of indirect methods have been devised for the estimation of certain aspects of body composition in man.

Isotopic Dilution Technique

The ready availability of stable and isotopic tracers at the end of the war stimulated investigation of total body composition in living man. Methods for estimation of total body water and total exchangeable sodium, potassium, and chloride have been developed and used extensively in both normal and diseased subjects.

In general the technique consists in administering a known quantity of tracer and allowing a period of time to elapse for mixing of administered tracer with non-tracer present in the body. Urine is collected quantitatively during this period, at the end of which a sample of serum is obtained for analysis. If tracer is designated as X°, and non-tracer as X, then

\[
\text{total exchangeable } X = \frac{X^\circ \text{ administered} - X^\circ \text{ excreted}}{\text{serum } X^\circ / \text{serum } X}
\]

Now if the ratio of serum X°/serum X is equal to whole body ratio of X°/X, total exchangeable X will be identical with whole body content. Fecal and cutaneous losses of X° are usually negligible. The time allowed for mixing has usually been 1 to 3 hours for deuterium oxide or tritium oxide, 4 to 24 hours for stable bromide or radiobromide, 18 to 24 hours for radiosodium, and 24 to 40 hours for radiopotassium. Bromide is substituted for chloride, since there is no convenient isotope of the latter. Antipyrine, or one of its derivatives, may be substituted for deuterium or tritium. Friis-Hansen et al. found, in a series of infants and children, that the volume of distribution of deuterium was 2% higher than that of antipyrine.

Although there is considerable evidence that the results of isotopic dilution measurements do approximate total body content in small laboratory animals, data for human beings must be qualified to a certain extent. Deuterium and tritium oxides mix with tissue water very rapidly, and there is in addition some exchange with nonaqueous hydrogen, leading to an overestimation of 0.5 to 4%. For bromide, sodium, and potassium, mixing is slow and often incomplete in the case of erythrocytes and central nervous system tissue, and very slow in the case of sodium in bone.

In the adult, it appears that the dilution method yields appropriate values for water, subject, of course, to the possible small discrepancy previously mentioned. The situation is not so clear in the case of the other isotopes: The ratio of total exchangeable content to actual content is 0.85 to 0.97 for potassium and chloride and about 0.7 for sodium. In the newborn infant correspondence is good for chloride and water and fairly good for sodium and potassium.

Of current interest is the amount of radiation delivered to the body during these procedures. For the short-lived isotopes, such as K⁴², Na²⁴, and Br⁸₂, and for tritium, the total dose is usually less than 0.2 roentgen-equivalent. Deuterium is of no concern since it is a stable isotope. Long-lived sodium (Na²²-physical half-life 3 years) presents a potential problem. Although most of the isotope is eliminated from the body of the adult with a biologic half-time of 11 days, a small fraction (less than 1%) is discharged very slowly with a half-time of about a year. Because of the very slow disappearance rate, this minute fraction accounts for as much as 10% of the total radio-
tion dose. Presumably this slow component is in bone. No data are available on the biologic half-life of Na$^{22}$ in infants.

**Whole Body Radiation Counter**

In recent years, instruments have been constructed by which the minute amounts of radiation emanating from the body can be accurately measured. This radiation arises from naturally-occurring radioactive elements ingested in food and water, and also from fall-out by-products of the atomic bomb explosions. Indeed, these instruments are now being used to assess certain aspects of the magnitude of the radioactive fall-out problem.

Of interest to the present discussion is the fact that the body content of potassium can be measured in this way. Three isotopes of potassium exist in nature, and one of these ($K^{40}$) is radioactive, with a physical half-life of $4 \times 10^9$ years. Potassium$^{40}$ constitutes 0.012% of total naturally-occurring potassium. Thus, an estimate of the amount of potassium present in the body can be obtained by measuring its $K^{40}$ content. Since the human body contains very small amounts of $K^{40}$ (about $10^{-2}$ μc) the measuring device must be unusually sensitive. Due to the extensive investigations of Anderson, Langham, and co-workers with the Los Alamos whole body counter, we now have more complete data on potassium content in man than for any other constituent. Some 1,600 people have been studied by these authors.

Figure 1 depicts the changes that take place in water, potassium, and chloride contents of the human body during fetal and postnatal life. These are the only constituents that have been studied systematically and in detail. (Total exchangeable sodium has been so studied, but this does not have a precise relationship to total body content.)

* The combination of these two factors results in a somewhat greater radiation dose than is the case for the other isotopes. Although a precise figure for skeletal dosage cannot be given at present, it is unlikely that this exceeds current tolerance limits.

**Water content** declines progressively throughout fetal life and early infancy. Recent data show that sex differences become apparent by 4 to 7 months of age. At this time the male/female ratio for body water is 1.04, on a per kilogram basis. At adolescence the sex difference becomes more evident, and there are wide differences between male and female adults, presumably because of differences in fat content. The decline in total body water during ageing also may reflect alterations in the amount of fat.

**Total body chloride** shows a similar trend as growth proceeds. Sex differences appear early in life (male/female ratio being 1.11 by 4 to 7 months of age) and are quite pronounced in early adult life. Admittedly, the isotopic dilution procedure may underestimate total body chloride by about 10% in the adult, but the general trend with age is nevertheless clear.

**Potassium**, on the other hand, shows a steady rise throughout the fetal and childhood periods. Sex differences, in the data available thus far, first become clearly apparent early in the second decade. Maximum values occur here, after which there is a gradual and progressive fall possibly reflecting, as in the case of total body water, an increasing adiposity. Some variation does occur within each age group, the standard deviations being about 10 to 15% of the means.

**Fat content**, as determined by chemical analysis, is of the order of 0.5 to 1% in early fetal life, increases slowly at first, and then very rapidly in the last trimester. Widdowson found that total body fat in the human newborn (12-16%) was higher than that of any of the other mammals she studied, including the guinea pig.

Data on total body fat in postnatal life will be presented in a subsequent section of this memorandum.

Again referring to Widdowson's studies on body composition in mammals, and to Hamilton's data on the rat fetus, the changes illustrated in Figure 1 for man are duplicated in other species. This interspe-
Fig. 1. Total body content of H₂O, Cl, and K in relation to age. Each point represents an average of several subjects. Symbols as follows: H₂O and K—combined sexes ○, males ■, females ◦; Cl—combined sexes □, males ▲, females ▲. Data for fetus and newborn are from Kelly et al. and Widdowson. Data for infants, children and adults are from the following sources: Water (deuterium or tritium dilution)—Friis-Hansen, Edelman et al., Prentice et al., Gilder et al. and Owen et al.; K⁺ counting—Anderson and Langham, chloride (Br⁻ or stable Br dilution)—Forbes et al., Cheek, Ikko et al. and Owen et al. One set of values has been omitted, namely, that for the 3-month fetus analyzed by Iob and Swanson. Although water content was in keeping with the general trend, low values for Cl (21 meq/kg) and K (9 meq/kg) were reported. The reason for these seemingly aberrant values is not clear.

eries correspondence is manifest not only in the direction of the change but also in the rate at which the changes occur at different periods of growth. The decline in water and chloride contents, and the increase in potassium content, are most rapid in early life, when growth is rapid; during later periods of decreased velocity of growth, changes in composition proceed more slowly. Moulton, impressed by the rapidity of compositional change in early life, announced in 1923 his theory of "chemical maturity." This theory states that at a certain time in the life of animals and men, body composition (fat-free basis) attains its adult value, where it then remains. Close inspection of his data reveals that composition does change slightly after this point is reached, but to much less a degree than in early life. As will be discussed later, changes in fat content continue to occur throughout most of adult life.

Changes in contents of water, potassium, and chloride appear comparable during growth in all mammalian species studied thus far. This is best demonstrated by the
**allometric** method whereby plots of log body content against log weight yield a series of straight lines. The resulting slopes, which really represent percentage increments of chemical growth, show a remarkable interspecies correspondence. The relative rate of change in body composition, as well as its direction, would thus appear to be independent of species; this rate may also reflect a fundamental property of maturing mammalian protoplasm.

The trends in body content of chloride and potassium illustrated in Figure 1 also serve to define approximately the changes in volumes of extracellular and intracellular fluid occurring during growth. The data of Friis-Hansen indicate that extracellular fluid accounts for about 70% of total body water in the 5-to-6-month fetus, 55 to 60% in the newborn infant, 44% in the one-year-old child, and 33% in the 3-to-16-year-old group. The magnitude of the extracellular fluid compartment (and of intracellular fluid, since this is calculated by subtraction) varies with the method used for its determination. Friis-Hansen used thiocyanate; others have used inulin, thiocyanate, bromide, and, of course, chloride.

Cheek has recently reviewed the subject of extracellular fluid and its measurement. This fluid compartment has been difficult to define anatomically; there has been much argument as to whether it should be considered to include cerebrospinal and joint fluids, and the fluid within the gut. No substance has yet been found that will leave the vascular compartment quickly after injection and yet be constrained from entering certain tissue cells, and it is doubtful that such a substance will be found. The extracellular fluid is the principal avenue connecting body cells with the outside world; it follows that a great many substances must be continually leaving and entering it at a very rapid rate. It is unlikely that the volume of distribution of any substance would coincide with this very active body fluid compartment.

One further consideration has been raised by the recent experiments of Peter-son et al. These authors measured extracellular fluid volume by the constant infusion technique (sucrose) over a period of 10 to 24 hours in a number of subjects. They found that rather large variations in calculated volume of extracellular fluid occurred in each of the subjects, the coefficient of variation averaging 8%. Only about one-fourth of this variation could be accounted for by technical errors; the authors consequently concluded that physiologic shifts in body fluids are continually taking place.

**Quantitative Roentgenography of the Skeleton**

Suggestions have been made from time to time that this method could be applied to the assessment of body calcium stores. It is well established that 99% or more of the total body calcium is in bone, and Mack et al. have calculated that about 80% of the total x-ray absorption by bone is due to the calcium present therein. A recent study has shown that the bones of malnourished Indian boys are less dense than those of American boys.

Schraer has recorded estimates of bone density (os calcis and phalanx) for children of both sexes between the ages of 7 and 20 years. A gradual increase in density occurs over this period. For the phalanx, density is higher in the female, while the reverse is true for the os calcis. Differences of 15% or more in bone mineralization can be detected by this method. Mainland has defined the multiple sources of error (soft tissue masking, irregular contour of bone, film position and processing, etc.) which are inherent in the roentgenographic technique. Barnett and Nordin have suggested the simpler technique of using the cortex/shaft ratio in femur and degree of biconcavity of vertebrae to assess the degree of osteoporosis.

**ESTIMATION OF TOTAL BODY FAT**

A number of methods for estimating total body fat have been tried. Some are designed to provide absolute values, while others can only yield comparative data.
Total Body Water Method

If it is assumed that the fat-free body or lean body mass (LBM) has a constant water content, and that neutral fat is stored dry, it becomes possible to calculate total body fat from the water content of the body. Since lean body mass of the adult contains 72% water,

\[
\text{LBM (kg)} = \frac{\text{total body water (kg)}}{0.72}
\]

Total fat is then body weight minus lean body mass.

In the newborn infant the denominator should be 0.82, for this is the water content of the lean body mass in this age group (Table 1). No data from carcass analysis are at hand for the older infant and child, and it is not known when the transition between infantile and adult body composition is complete. Moulton\(^6\) has suggested that this is accomplished at about age 3 years.

The validity of the calculation depends on the constancy of composition of lean body mass. The few chemical analyses done in adult man, and the many carried out in animals, support this contention, but extremely obese human subjects have not been analyzed. Studies\(^66,68\) on obese subjects before and after weight reduction reveal that the tissue lost by these patients can be calculated to contain 15% water and 23 meq of potassium per kilogram; if this be the case, either the water content of the lean body mass changed during weight reduction, or lean tissue was lost in addition to fat.

Densitometric Method

Since fat has lower density than lean tissue, Behnke et al.\(^60\) proposed that fat content could be estimated from a measurement of the density of the whole body. The nearer this figure is to the density of fat (0.901) the fatter the subject, and those subjects whose density approaches that assumed for the lean body (1.097) are obviously quite lean. By using an appropriate formula, such as the one given by Keys and Brozek,\(^61\) an estimate of total body fat can be obtained.

Body density is usually determined in the adult by weighing the subject in air and immersed in water, with appropriate corrections for residual air in lung and intestine. Zook\(^62\) succeeded in measuring specific gravity in a group of 5-to-19-year-old boys, and Parízková\(^63\) has published values for density of 9-to-17-year-olds of both sexes. The former article includes a bibliography of the older literature on specific gravity.

Body volume of adult human subjects has been determined by Siri\(^64\) employing a method of helium displacement, and the method of air displacement has been used for animals.\(^65\) If body volume is known, density can be calculated and an estimate of fat made.

Several difficulties present themselves in the use of the densitometric method for estimating body content of fat. The actual technique of measurement is rather difficult. In addition, the density of the lean body mass has never been measured directly, the value used being derived from data for individual tissues. For the infant and child, this value undoubtedly differs from that of the adult.

For both densitometric and total body water methods, as originally used, the assumption is made that the lean body mass has a constant composition. This assumption receives support from studies on small animals, particularly those of Rathbun et al.\(^66\) More recent studies\(^67,68\) of a variety of isolated human tissues reveal that both density and water content can be related to fat content.

If both methods are valid, they should yield comparable results. Osserman et al.\(^69\) found that this was indeed the case. Behnke and Siri,\(^70\) on the other hand, in studying a series of 31 young men, found an average fat content of 22% by total body water and 18% by densitometry. In a series of young women, Young et al.\(^71\) found an average fat content of 28% by total body water and 25-29% by densitometry, depending on the particular formula used for calculation. Tan-
ner pointed out that any lack of correspondence between these two methods must inevitably result in a certain error in estimation of fat, and that this error is appreciable.

Is the concept of a constant "lean body mass," to which fat is added to a greater extent in the obese than in the normal, a valid concept, or is it merely a convenient abstraction? The fact that individual tissue samples show a high degree of constancy when composition is calculated on a fat-free basis does not allow one to assume categorically that the total lean body mass does not change as fat is added to or subtracted from the organism. Keys and Brozek reported that the density of the tissue actually gained or lost under controlled conditions in man is 0.93 to 0.95 (pure fat = 0.90) and that the calculated composition of this tissue is 64% fat, 23% cellular matter, and 13% extracellular fluid.

In the light of these findings, a new concept has arisen, namely, the "standard reference man," containing 14% fat, 61% water, 19% protein, and 6% minerals. A given adult subject differs from this hypothetical individual only in having a different proportion of adipose tissue, which is assumed to be 62% fat, 31% water, and 7% protein. Keys and Brozek have derived a formula based on this concept for calculating fat content.

Ljunggren and co-workers proposed a variation of this concept, in which the body is divided into "obesity tissue" consisting of fat and its supporting connective tissue, and "non-obesity tissue" which is the remainder of the lean body mass. "Obesity tissue" is considered the main variable affecting body composition.

Siri has proposed a new formula, which embodies values for both density and body water. With both of these parameters at hand, the resultant calculation for body fat is not affected by variations in tissue hydration, since the assumption of compositional constancy of the hydrated lean body mass is no longer necessary. However it is still necessary to assume a constant ratio of mineral/protein in the body, in other words a constant density for lean body solids.

The investigator today is thus faced with the problem, once the density measurement has been made, of deciding which of several formulas now available should be used in deriving a value for actual fat content. Although body density can be measured with precision (standard error 0.2%) calculated fat content will vary with particular formula employed. In the study of Young et al., employing five different formulas, calculated fat content varied from 25 to 29%. Lim and Luft studied a group of male adults. The Siri formula yielded results for fat content some 6 to 7% higher than did the Keys-Brozek formula. Taking 20% for average fat content, this means that the discrepancy between the two methods of calculation is of the order of 30%. One can hardly disagree, therefore, with Lim and Luft's conclusion that "the true values for body fat cannot be stated with certainty at the present time."

The matter of relative size of the skeleton (e.g., the "small," "medium," and "large" frame referred to in weight tables for adults) presents another difficulty for both the densitometric and body water methods. The existence of this variable is evident from the data on calcium (Table I). Since the skeleton has a much lower water content and a much higher density than soft tissues, it is evident that variations in skeletal size would alter both density and water content of the lean body mass. Despite all of these objections, both the densitometric and total body water methods are currently in use as a first approximation of fat content of the adult. It is reported that certain physiologic phenomena, such as basal metabolism and cardiac output, correlate better with fat-free weight than total weight or surface area. Such little use of these methods has been made in childhood that an evaluation cannot be made at this time.
Creatinine Coefficient

A number of years ago Talbot proposed the use of the creatinine coefficient (creatinine excretion expressed as mg/kg/24 hr) as an index of obesity. He found this value to be inversely proportional to the degree of obesity as judged by weight and clinical criteria. Others have determined this coefficient in infants and children of various ages. The coefficient is higher in adolescent boys than girls; this and other observations have led to the contention that creatinine excretion is proportional to the muscle mass of the body. Recently Talso et al. and Muldowney et al. found a high correlation between creatinine excretion and total body potassium \( r = 0.8 - 0.9 \); Miller and Blyth found a high correlation between densitometrically determined lean body mass and creatinine excretion in adults. Kumar et al. have related creatinine excretion to chemically determined lean body mass in rats, but pointed out the need for using a low creatinine diet and a urine collection period of at least 48 hours for accurate results.

The situation in the young infant is not so clear. The data of Catherwood and Stearns indicate a good correlation between creatinine excretion and body weight in full-term infants. Cranny and Cranney, on the other hand, found large variations among premature infants, with a range of as much as fivefold in infants of comparable weight. Kennedy’s recent study of hospitalized children revealed a rather poor correlation between creatinine excretion and total exchangeable potassium.

The creatinine method offers the obvious advantage of ready availability, without the need for elaborate technical procedures, though some workers have failed to follow the precautions suggested by Kumar et al. From the biochemical point of view, creatinine production and excretion is far from a simple process, making it unlikely that the size of the lean body mass is the only factor which determines excretion rate.

Measurement of Subcutaneous Fat Layer

Although the precise fraction is not known, it is likely that a considerable proportion of the adipose tissue of the body is located subcutaneously. Two methods for estimating subcutaneous fat have been used in man: measurement of skinfold thickness (skin plus subcutaneous tissue) and soft tissue roentgenography. Garn has reported that the two methods yield comparable results. For the former method, special calipers are needed—calipers designed in such a way that constant pressure is exerted at all jaw widths. The skinfold method can provide information about the relative distribution of subcutaneous fat from region to region whereas the densitometric and body water methods give an estimate of total amount of body fat.

In the adult male, Brozek and associates and Pascale et al. have reported a high degree of correlation between the skinfold and densitometric methods. Skinfold thickness increases with weight and is correlated with densitometrically determined fat content in adult women. Forbes et al. found that skinfold thickness could be correlated with fat content as determined by K content. It would appear that this relatively simple measurement could serve as an index of obesity, at least in the adult.

The studies of Stuart and Sobel, Garn, Reynolds and Grote, and Pett and Ogilvie reveal that subcutaneous tissue thickness varies during infancy and childhood. Maximal values occur at about one year of age, and in adolescence, and there is a steady increase during the adult years. Sex differences become apparent in early childhood.

In the recent flurry of concern about adiposity in the modern adult, many have failed to appreciate the fact that the human

* Analysis of one full-term newborn infant (fat content 14% of body weight) revealed that 42% of the body fat was located subcutaneously. In the guinea pig, subcutaneous fat makes up 12% of total body fat in males, and 20% in females; the relative proportion of total body fat present in this site does not vary appreciably with the degree of fatness of the animal.
infant is also fat. Indeed, subcutaneous tissue thickness in certain areas of the body exceeds that of the adult male. This is well illustrated by the data of Pett and Ogilvie obtained from a random sample of the Canadian population (Fig. 2). Obviously the 5-mm triceps skinfold thickness in the 2-year-old represents a far greater relative proportion of subcutaneous fat than does the 4-mm layer in the 40-year-old male, or for that matter, the 8-mm layer in the female.

The technique involved in making these measurements is discussed by Keys and Brozek and Tanner.

Use of Fat-soluble Indicators

A number of inert gases are much more soluble in fat than in lean tissue. Thus the volume of distribution of such substances within the body should logically be a function of total fat content. Lesser et al. have recently extended their earlier work on cyclopropane absorption in animals to include human adults. This gas is 34 times more soluble in fat than in lean tissue. Results obtained in study of four male and two female subjects indicated values for fat content which were, on the average, 12% lower than those derived by the total body water method. Since the theoretic basis for the cyclopropane method is sound, this discrepancy does not necessarily lead to its invalidation.

The procedure is time-consuming and technically difficult. Equilibration is not yet complete in 8 hours, so repeated analyses of the inspired gas and a complicated mathematic treatment are necessary in order to obtain an answer.

Radiokrypton has also been suggested, though no extended series of observations has been reported. This method suffers from the same technical difficulties as the cyclopropane method, and introduces the added feature of radioactivity. Behnke, noting the fact that nitrogen is five times more soluble in fat than in water, estimated

Fig. 2. Average skinfold thickness as a function of age and sex, from the Canadian survey of Pett and Ogilvie. The measurement includes a double layer of skin plus subcutaneous tissue.
body fat by measuring the amount of nitrogen washed out of the body during 12 hours of breathing pure oxygen.

These methods offer considerable theoretic advantage over those discussed previously in that they constitute a direct, rather than an indirect, method of estimating fat content. It is unfortunate that they involve such an intricate technique.

**Total Body Potassium Method**

On the assumption that the lean body mass has a constant potassium content, and that neutral fat does not bind electrolyte, it should be possible to estimate total body fat from the potassium content of the body. Evidence from chemical analyses supports the contention that the adult lean body mass has a relatively constant potassium content in both man and animals, though the values vary from one species to another. Kulwich et al. found a high correlation between $K^{40}$ activity and lean weight in meat samples. Several investigators have proposed that this method could be used as an index of body fat content.

The potassium content of the body can be measured in two ways: by the $K^{42}$ dilution technique, or in the whole body scintillation counter. The calculation of fat content is made in a manner analogous to that employing total body water, namely,

$$LBM = \frac{\text{total K content}}{\text{concentration of K per kg of LBM}}$$

Figure 3 is a graph of percentages of fat against age, calculated in this manner from

![Figure 3. Average percentages of fat in the body as a function of age and sex, calculated from the K$^{42}$ data of Allen, Anderson, and Langham. The curves bear a rough similarity to those of Figure 2.](image-url)
the extensive data of Allen, Anderson and Langham. It is of interest that Parízkova’s study of body density in children yielded results comparable to those depicted in Figure 3, such as a clear cut sex difference, and a rapid rise in body density (and hence a fall in fat content) in the 15-to-16-year-old male.

The K\textsuperscript{42} dilution method may underestimate true potassium content to a certain extent. Reported values are 85%, 95%\textsuperscript{26} and 97%\textsuperscript{27} of those determined by whole body counting in the adult. Comparison with values from carcass analysis yields a figure of 85% for both the adult\textsuperscript{6} and the newborn infant.\textsuperscript{30} Furthermore, carcass analysis reveals a lower potassium content per kilogram of lean body mass for the newborn infant than for the adult (Table 1). The same is true for animals.\textsuperscript{2,3,12} It is not known at what age the transition from infantile to adult composition is complete in man. For the older child and adolescent, however, the error involved is probably rather small.

Comparisons between the potassium and total body water methods show that somewhat larger values for fat content are obtained by the former.\textsuperscript{*}

The whole body scintillation counter is an expensive and intricate instrument, and only a few are in existence. However, the actual procedure of measuring the adult subject requires only a few minutes (3 to 30, depending on the instrument) and involves no discomfort to the subject.

Currently there is a great deal of interest in fat determination in living man, due primarily to the postulated relationship between obesity and disease and longevity.

* This is to be expected, since the potassium content of the fat-free component of adipose tissue is somewhat less than that of lean tissue while the water content is comparable for both (see second preceding footnote). Thus, in an obese individual, the potassium content of the total lean body mass might be somewhat less than that of a leaner subject, and so lead to an overestimation of fat content by the formula just given. On the other hand, deuterium and tritium undergo exchange with non-aqueous hydrogen, so that the total body water method would tend to underestimate fat content. Unfortunately, with the exception of the use of fat soluble indicators, all of the methods now available are indirect in nature and depend for their worthwhileness on the validity of the underlying assumptions that must be made. There is no way at present to test these assumptions other than by comparison with carcass analysis (and these are all too few in number and include no representative subject between the newborn infant and adult) or by analogy with data from animals. Although it is true that the individual tissues do not differ greatly in composition from one mammalian species to another, it is by no means certain that the relative amounts of the various tissues are the same. This is indeed the case for skeleton; in the rat this tissue comprises about 7% of total body weight,\textsuperscript{102} and in man 16%.\textsuperscript{19}

Investigators in this field are wont to compare one method with another and to use such comparisons as a basis for drawing conclusions as to the accuracy of one of the methods. Since no one method has as yet been shown to possess inherent precision, such comparison would appear fruitless.\textsuperscript{*}

One other consideration has to do with the analytic error involved in the various methods. For example, a determination of total body water involves three measurements: amount of substance injected, amount excreted, and serum concentration (a fourth is necessary if a pre-injection serum blank is used). All of these measurements are subject to analytic error. The over-all error is probably of the order of 5%. This will inevitably lead (except for a subject whose fat content is 50% or greater)

* A study of the correlations of various body measurements with fat content determined by K\textsuperscript{42} counting has recently been carried out in the author’s laboratory by Dr. James Barter (unpublished). In a series of 50 adult males (20 to 55 years old) the following correlations with total fat were obtained: body weight 0.85, skinfold thickness (av. of 6 sites) 0.73, abdominal circumference 0.90, buttocks circumference 0.87, chest circumference 0.86. Over the weight range of 56-102 kg, total fat (kg) = 0.815 weight (kg) – 36.7, with standard error of estimate ± 5.3. Females have a higher fat content for a given body weight.
to a larger error in estimation of fat content than was involved in the measurement of total body water. *

Most of the studies of fatness-leanness have been done with adults. It is to be hoped that some of the newer methods will be applied to infants and children. A readily applicable index of this aspect of body composition would be most helpful in assessing nutritive status.

**CAN BODY COMPOSITION BE CHANGED BY DIET?**

The question of whether body composition can be changed by diet has intrigued pediatricians for many years. Metabolic balance studies with normal infants have shown with monotonous regularity that the retention of nitrogen and minerals varies directly with intake, and calculations based on these data showed that the greater the intake of particular substance the greater was its final concentration per unit weight of body. The logical conclusion was that storage of protein and minerals could occur, and the concept of “supermineralization” developed. General nutritional theory embraced the concept of “reserve” supplies of nutrients, and cow’s milk with its greater content of protein and minerals was thought to possess a definite advantage.†

It has been known for a long time that the calcium content of the body can be altered by diet, 104, 105 and recent roentgenographic observations show that the bones of malnourished Indian boys are less dense than those of American boys. The fat content of the body can be changed by diet. Qualitative changes in composition of body fat can also be produced by altering the type of fat fed. 106

Recently the question of whether the composition of other body tissues is subject to dietary influence (short of actual pathologic states) has been once again taken up by a number of investigators. The experiments of Wallace *et al.* 107 with the rat, and of Filer *et al.* 108 with the pig, can be offered as examples. Diets of varying protein, fat, and ash content were fed to growing animals, and the resultant composition of the body was determined by direct chemical analysis. The entire body was analyzed in the case of the rat, the exsanguinated eviscerated carcass of the pig. Despite rather wide variations in diet, these experiments demonstrated that tissue composition generally remained rather constant when the values were calculated per unit fat-free tissue. Thus a unit weight (fat-free) of animal manifests a particular percentage composition regardless of a varying intake of essential nutrients. The one notable exception was calcium, which varied with the amount contained in the diet. This was true for both the rat and pig. As Wallace *et al.* have put it, “The composition of the body achieves an independence from the environment.”

Widdowson *et al.* 109 have recently re-examined this question. By seeing to it that nursing rats received either a large or small intake of milk from a very early age, they were able to observe a number of consequences. The well-fed animals were heavier, longer, and fatter at weaning, * and it is of great interest that these differences persisted to a degree after weaning in the face of ad libitum feeding. In the experience of these authors this early feeding experience had a profound influence on body size and degree of fatness later in life. Moreover, these changes occurred, in contrast to the experiments cited above, on a diet of normal composition. The implications in human nutrition are obvious.

It was also found that such other pa-

---

* Assume body weight 60 kg, total water content 36 l; then fat = 60-36/0.72 = 10 kg, or 16.7% of body weight. If total water is figured at 34.2 l (5% less than 36 l), fat = 12.5 kg, or 20.8%. The latter value for per cent fat is 125% of the former. In general, since fat weight involves a subtraction of lean body mass from total weight, the thinner the person the greater will be the error, assuming a fixed error in the measurement of total body water.

† Cf. Fomon’s critique of metabolic balance methodology. 108

* The well-fed animals weighed about twice as much and contained about four times as much fat as the poorly fed ones.
rameters of maturation as skeletal ossification, tooth eruption, testes size, and time of vaginal opening were all accelerated in the well-fed animals. Slight differences were also found in chemical composition of muscle, brain, and bone; but unfortunately not enough data are given for these features to allow one to judge whether the changes were significant. These results are in keeping with the well-known observation that obese children show some acceleration in height and in maturation.

The recent experiments of Heggeness et al. on the rat have confirmed these observations in part. Overfed nursling animals grew faster, and laid down more fat, than underfed animals. However, percentage of water in the fat-free body was unchanged, as was the rate of development as indicated by hair appearance and eye opening.

The feeding regimen, as well as the total amount of food, is also important. Heggeness has found, for example, that weanling rats fed a high carbohydrate diet at a level just sufficient to maintain body weight differ from those fed ad libitum. These differences are manifested by lack of calorigenic response to glucose feeding, by a more efficient use of diet (weight gain per gram of food consumed), and by a tendency to store more fat. Experiments such as these illustrate the manifold complexities of dietary factors which affect body composition.

In such experiments, the frames of reference for expressing composition must be examined. With the exception of fat and calcium, it has been difficult to produce striking changes in percentage composition by altering the diet. When values are expressed on a per animal basis, this relative constancy disappears. Thus, high-protein diets result in larger animals and, therefore, in more total accumulation of protein over a period of time than low-protein diets; high-caloric diets produce fatter animals, and the same trend is noted for some of the mineral constituents. It is in this area of interest that the metabolic balance method may have some usefulness. Since the size of the skeleton varies with diet, it is to be expected that to a certain extent the retention of other materials that go into bone—sodium, magnesium, phosphorus, and protein—will show concordant changes.

A word should be said about the phenomenon of adaptation to varying nutritional situations. Observations on children in technologically underdeveloped areas reveal that these people are small in size when compared to Western Europeans and Americans. Thus retardation in growth rate can be considered as an adaptation to the inadequate food supply. Newman has found, for instance, that among adults the ratio of body weight to surface area decreases as the climate becomes warmer; this is in essence an adaptation to climate. Thus the phenomenon of adaptability is certainly not limited to lower animals, and though it may not be as highly developed in man, it must be considered and dealt with in evaluating studies of human nutrition.

Finally, note should be taken of recent attempts to apply some of the newer methods for the assessment of body composition to the study of infants and children. Osler and Pedersen determined total body water in a series of newborn infants born to diabetic mothers, with the interesting result that these infants have a subnormal water content, and thus probably an increased amount of fat. Smith made a study of total body water in malnourished infants. Composition underwent marked changes during recovery, including periods when gain in body weight was poor. Parízková has measured body density in a series of normal and obese children; density was markedly reduced in the latter group.

CONCLUDING REMARKS

At attempt has been made in this review to present the various methods for estimation of body composition which are available to the modern investigator. Not all of them are well suited to the study of infants and children, and some require an intricate technology. Generally, they do not com-
mand a high degree of precision, a statement which is all too true (though only recently admitted) for the time-honored metabolic balance technique. The very slow growth rate of man makes for great difficulty in applying seriatim any technique for estimating the composition of normal growth over short intervals of time. Nonetheless, assessment of gross body composition is an important tool for nutritional research and for the study of population groups, and is in fact prerequisite to the understanding of some modern nutritional problems. It is to be hoped that pediatric investigators will make fuller use of the methods now at hand, and even partake in the development of newer methods yet to come.

REFERENCES

31. Christian, J. R., et al.: Total body water and...


90. Pascale, L. R., et al.: Correlation between thickness of skin folds and body density in 88 soldiers. Brozek.


107. Wallace, W. M., Weil, W. B., and Taylor, A.:


Acknowledgment

I should like to acknowledge the generous cooperation of Dr. E. M. Widdowson in making available to me the detailed results of her studies on body composition of man and various mammals, and that of Dr. W. H. Langham in sending me detailed data on K⁺ measurements.
METHODS FOR DETERMINING COMPOSITION OF THE HUMAN BODY: With a Note on the Effect of Diet on Body Composition

Gilbert B. Forbes

Pediatrics 1962;29;477

Updated Information & Services

including high resolution figures, can be found at:

http://pediatrics.aappublications.org/content/29/3/477

Permissions & Licensing

Information about reproducing this article in parts (figures, tables) or in its entirety can be found online at:

https://shop.aap.org/licensing-permissions/

Reprints

Information about ordering reprints can be found online:

http://classic.pediatrics.aappublications.org/content/reprints

Pediatrics is the official journal of the American Academy of Pediatrics. A monthly publication, it has been published continuously since 1948. Pediatrics is owned, published, and trademarked by the American Academy of Pediatrics, 141 Northwest Point Boulevard, Elk Grove Village, Illinois, 60007. Copyright © 1962 by the American Academy of Pediatrics. All rights reserved. Print ISSN: 0031-3998.
METHODS FOR DETERMINING COMPOSITION OF THE HUMAN BODY: With a Note on the Effect of Diet on Body Composition

Gilbert B. Forbes

Pediatrics 1962;29;477

The online version of this article, along with updated information and services, is located on the World Wide Web at:

http://pediatrics.aappublications.org/content/29/3/477