THE CHEMICAL COMPOSITION OF THE ADULT HUMAN BODY AND ITS BEARING ON THE BIOCHEMISTRY OF GROWTH*

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The amounts of nutrients contained in the adult human body represent the integration of the day to day accretions from the time of conception to the termination of growth. These accretions are usually determined by balance experiments carried out at different periods of growth and are assumed to measure the net requirements of the respective nutrients with due consideration of the synthesis and transformation of organic nutrients in metabolism. Thus, the accretion of fat does not measure a fat requirement, but the accretion of protein and of the essential mineral elements may. Whether it does, or whether it does not, will depend upon the capacity of the body to store the nutrient in amounts considerably greater than current needs. The capacity of the body to store protein is strictly limited; so that nitrogen balances secured on a growing child after a reasonable period of adjustment to a liberal intake will measure reasonably well the amount needed for maximum growth in terms of net protein. The capacity of the body to store calcium is relatively enormous, far in excess of the needs of the soft tissues of the body and quite probably in excess of the need for a rigid and strong skeletal structure. Calcium balances on the child subsisting upon a liberal calcium intake may or may not measure the day to day need for net calcium, depending upon the degree of saturation of the skeleton in calcium salts,.a condition that may vary with metabolic factors as well as with the food supply.

The extent to which metabolic balances of nitrogen, calcium, iron, etc., actually measure the day to day requirements in terms of net nutrients[1] can be judged by comparing their total integration throughout growth with the composition of the mature body with respect to them. However, information on the composition of the adult human body is strangely contradictory and incomplete.

The situation may be illustrated by the information on the content

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[1] By net protein, net calcium, etc., is meant the dietary supply minus all the losses to which the respective nutrient is subjected in the course of digestion, absorption, and assimilation as tissue constituents.

of calcium and phosphorus. The calcium and phosphorus contents of the adult human body have been variously estimated, often from undisclosed sources. Aron in 1908 (1) stated that adult man contains 4 per cent of ash, of which 40 per cent is CaO, the calcium content thus being 1.14 per cent. In 1919, Hackh (2) estimated the calcium and phosphorus contents of man at 1.90 and 0.95 per cent, respectively. 4 years later, Vernadsky (3) presented estimates of 1.4 per cent of calcium and 0.8 per cent of phosphorus, based on Volkmann's data published in 1874 and cited by Carl Voit in Hermann's "Handbuch der Physiologie," Leipzig, 1881. In a paper published in the following year, Vernadsky (4) cited some figures of Bertrand, reported in 1920; *i.e.*, 1.38 per cent of calcium and 0.63 per cent of phosphorus. Gilbert and Posternak (5) state that the body of average adults contains about 1600 gm. of phosphoric acid, equivalent for a 70 kilo man to a phosphorus content of 1.0 per cent. From data secured from a rather complete collection of Ceylonese skeletons, Nicholls and Nimalasuriya (6) estimate the average calcium content of the adult male of Ceylon as 1.65 per cent and of the adult female, 1.52 per cent. Less direct calculations for the adult European led to values of 1.84 per cent calcium for the male and 1.34 per cent for the female. Leitch (7), on the basis of assumptions that seem none too probable, has calculated that the adult human body contains 36 gm. of calcium per kilo, or 3.6 per cent. From the fragmentary evidence available in the literature, Mitchell and Curzon (8) estimated the calcium content of man at 1.5 per cent, and at about the same time Shohl (9) presented an estimate of 1.66 per cent calcium and 0.96 per cent phosphorus.

Reflecting the confusion prevailing in the literature concerning the mineral content of the adult human body, Sherman, in his classical work, "Chemistry of food and nutrition," has estimated the calcium content at 2 per cent in the 1st and 2nd editions, 1.5 per cent in the 3rd, 4th, and 5th editions, and 2.2 per cent in the 6th and last edition published in 1941. The phosphorus content is set at 1.0 per cent up to the last edition, when it was raised to 1.2 per cent.

The scientific importance of information on the chemical composition of the adult human body and the wholly unsatisfactory character of that available prompted the authors to undertake the investigation reported in this paper. The plan involves the analysis of a number of human cadavers in the age range of 20 to 50 years and in satisfactory nutritive condition. Since such specimens are not readily available, publication of the results obtained on single specimens seems warranted.

Methods and Materials

The cadaver was obtained through the courtesy of Dr. Otto Kampmeier of the Department of Anatomy, College of Medicine, University of Illinois, to whom grateful acknowledgment is made. It was that of a white man 35 years of age, 70.55 kilos in weight, and 183 cm. tall. Other measurements taken were the following: stem length (sitting height) 99.8 cm., shoulder (biacromial) width 35.3 cm., chest circumference at the level of the upper part of the xiphoid process 87.2 cm., and greatest distance between iliac crests 30.4 cm.

Death was due to an acute heart attack (decompensation or failure); postmortem examination performed by Dr. A. R. Cooper of the Department of Anatomy revealed passive congestion of both lungs, especially the lower lobes, and a moderately enlarged heart, showing evidence of chronic mitral valvulitis with mitral insufficiency or incompetency. "There were also a few small atheromatous white nodules in the lining of the first (ascending) part of the aorta, but the heart muscle showed no nodules. The twelfth rib on each side was only about 3 cm. in length, and the costal border was formed by the 9th ribs instead of the 10th." No other pathology or abnormality was noted.

Under the supervision of Dr. Cooper, the cadaver[2] was dissected into the various organs and tissues upon which separate weights and chemical analyses were desired. No attempt was made to remove all of the residual blood from the organs, although as much was removed as could be done by manual manipulation. The ulna, tibia, and ninth rib from the left side were analyzed separately from the other bones.

The samples were analyzed for moisture, nitrogen, ether extract, ash, phosphorus, and calcium by the official methods of the Association of Official Agricultural Chemists, except that in some of the soft tissues calcium was determined by a modification of the ceric sulfate method of Larson and Greenberg (10). The heats of combustion of all samples but the teeth were determined with the Parr adiabatic oxygen bomb calorimeter.

EXPERIMENTAL

Table I contains the values secured on the chemical composition of the organs and tissues analyzed, together with the relative weights of each with reference to the total body. The last row of figures relates to the composition of the entire body, which contained 67.85 per cent moisture, 12.51 per cent ether extract, 14.39 per cent protein (N $\times$ 6.25), 4.84 per cent ash, 1.596 per cent calcium, 0.771 per cent phosphorus, and a heat of combustion equivalent to 1.93 kilocalories per gm. Only 0.41 per cent is unaccounted for.

The skeleton, making up 14.84 per cent of the body weight, contains 30.1 per cent of the dry matter, 19.5 per cent of the fat, 18.6 per cent of the

[2] The body was preserved only by freezing until dissection was started about 6 weeks after death.

protein, and, with the teeth, 85.7 per cent of the ash, 99.0 per cent of the calcium, and 90.0 per cent of the phosphorus. The striated muscles constituted 31.56 per cent of the body weight, and contained 38.8 per cent of its water, 19.2 per cent of its dry matter, 8.1 per cent of its fat, 34.6 per cent

TABLE I

Chemical Composition of Adult Human Body

Parts analyzed	Per cent of total body	Chemical composition						Heat of combustion
		Water	Ether extract	Crude protein (N × 6.25)	Ash	Calcium	Phosphorus	
		per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*calories per gm.*
Skin	7.81	64.68	13.00	22.19	0.68	0.0205	0.060	2.292
Skeleton	14.84	31.81	17.18	18.93	28.91	11.02	4.83	2.497
Teeth	0.06	5.00*		23*	70.90	24.42	11.81	
Striated muscle	31.56	79.52	3.35	16.50	0.93	0.0099	0.116	1.239
Brain, spinal cord, and nerve trunks	2.52	73.33	12.68	12.06	1.37	0.0188	0.352	1.905
Liver	3.41	71.46	10.35	16.19	0.88	0.0102	0.148	2.196
Heart†	0.69	73.69	9.26	15.88	0.80	0.0078	0.113	1.824
Lungs‡	4.15	83.74	1.54	13.38	0.95	0.0116	0.114	0.985
Spleen	0.19	78.69	1.19	17.81	1.13	0.0079	0.217	1.193
Kidneys	0.51	79.47	4.01	14.69	0.96	0.0130	0.174	1.326
Pancreas	0.16	73.08	13.08	12.69	0.93	0.0143	0.155	1.979
Alimentary tract	2.07	79.07	6.24	13.19	0.86	0.0125	0.115	1.339
Adipose tissue	13.63	50.09	42.44	7.06	0.51	0.0116	0.048	4.165
Remaining tissues								
Liquid	3.79	93.33	0.17	5.68	0.94	0.0054	0.066	0.382
Solid	13.63	70.40	12.39	16.06	1.01	0.0675	0.053	2.040
Contents of alimentary tract	0.80							
Bile	0.15							
Hair	0.03							
Total body, weighing 70.55 kilos	100.00	67.85	12.51	14.39	4.84	1.596	0.771	1.930

* Assumed.

† Somewhat enlarged.

‡ Somewhat congested.

of its protein, 5.8 per cent of its ash, only 0.2 per cent of its calcium, but 4.5 per cent of its phosphorus. Of the 1126 gm. of calcium in the entire body, all but 12 gm. are located in the bones and teeth, and probably one-half of this small residue is located in the ligaments and tendons (the solid "remaining tissues"). The ratio of calcium to phosphorus in the entire body was 2.07:1.

The total heat of combustion was 136,163 kilocalories.

The composition of the skeleton and of the three bones analyzed separately, computed on the bases of fresh weight, dry weight, dry and fat-free weight, and ash, is summarized in Table II. These data will be used in assessing the nutritional status of the cadaver specimen with reference to calcium.

Normality of Specimen—The significance of the data presented in the preceding section to any study of the biochemistry of growth will depend upon the normality of the material analyzed, particularly with reference

TABLE II

Chemical Composition (Per Cent) of Bones on Different Bases

Constituent	Fresh basis	Dry basis	Dry, fat-free basis	Ash	Fresh basis	Dry basi	Dry, fat-free basis	Ash
	Left tibia				Left ulna			
Moisture	16.28				12.51			
Ether extract	36.39	43.47			17.80	20.35		
Crude protein	15.81	18.88	33.40		20.88	23.87	29.96	
Ash	31.40	37.51	66.34		44.60	50.98	64.00	
Calcium	11.92	14.24	25.18	37.96	17.56	20.07	25.20	39.37
Phosphorus	5.28	6.31	11.16	16.82	7.61	8.70	10.92	17.06
	Left ninth rib				Total skeleton			
Moisture	26.31				31.81			
Ether extract	7.82	10.61			17.18	25.20		
Crude protein	23.31	31.63	35.39		18.93	27.76	37.10	
Ash	37.90	51.43	57.54		28.91	42.40	56.67	
Calcium	14.77	20.04	22.42	38.97	11.02	16.16	21.61	38.12
Phosphorus	6.29	8.54	9.55	16.60	4.83	7.09	9.48	16.72

Ca to P ratio, tibia 2.257, ulna 2.307, rib 2.348, total skeleton 2.28.

to nutritional status. The latter is obviously difficult to assess, but the attempt to do so seems well worth while.

The age-height-weight relationship, when applied to Edwards' (11) nomogram, indicates that the subject was about 11 per cent underweight. However, as Edwards points out, actuarial records show that there are only small differences in mortality ratios (ratios of actual to expected deaths) within a range of 15 per cent above and below the average weight, so that the observed deviation of 11 per cent, if it is anything more than an error of sampling, can hardly indicate a considerable impairment in nutritional status.

An application of the nutritive index of Cowgill and Drabkin (12),

$N = W^{\frac{1}{3}}/L$, in which W is the body weight in gm. and L is the stem length or sitting height in cm., leads to a value of 0.414, somewhat less than the average value of 0.45. However, the measured stem length of this subject, 99.8 cm., seems much too high for his height, 183 cm. From the DuBois data, Cowgill and Drabkin obtained the following simple expression relating height H to stem length S, both being expressed in cm.; $S = 0.4H + 10.5$. Applied to the cadaver analyzed, the stem length becomes 83.7 cm., 16 per cent less than that observed. The latter value is 5.7 times the average deviation of calculated stem lengths from measured ones and is highly significant statistically if the distribution of stem lengths is symmetrical. The difficulty in measuring stem length in a lifeless body may be responsible in large part for the 16 per cent discrepancy between expected and observed stem lengths. If the stem length is taken as 83.7 cm., the nutritive index becomes 0.494, being quite within the normal range.

If adequate data on well nourished human subjects were available for comparison, the water and fat content of the specimen analyzed should be indicative of general nutritional status. The total water content of 67.85 per cent is higher than many values reported in the literature, but is lower than some: the source or antecedents of most of these values are obscure. From a study of old German analyses, Albu and Neuberg (13) estimate the average water content of adult man to be 58 per cent. McQuarrie (14) in his review of water metabolism in health and disease states that "Varying somewhat with the amount of fat present, the body of the adult contains between 58 and 65 per cent water." Moleschott (15) gives the water content of a 30 year-old man weighing 63.6 kilos as 67.6 per cent. The water content of a man weighing 65 kilos is estimated by Skelton (16) from previously published German data as 63 per cent. This is practically the same as the value given by Shohl (9), 63.1 per cent. Lavietes *et al.* (17) arrive at a higher value, 70 per cent, on entirely different evidence. In an unpublished experiment on forced urea feeding, the urea was found to distribute itself throughout approximately 70 per cent of the body weight of a normal subject, and in later experiments on the water exchange in humans, an assumption that the water content of the body is 70 per cent of the body weight permitted good agreement between changes in body weight predicted on this basis and the observed changes in weight. Rowntree (18) sponsors a higher water content of the adult of 75 to 80 per cent.

The fat content of 12.5 per cent for the cadaver analyzed lies about midway between the unbelievably low value of 2.5 per cent given by Moleschott (15) and Shohl's estimate (9) of 19.5 per cent. In the absence of other comparable data on man, it may not be out of order to state that Shohl's value of 19.5 per cent fat would represent a considerable degree of fattening in a fully sexed male farm animal.

The nutritional status with reference to minerals of the subject of this experiment may be assessed by considering the weight of skeleton and the composition of skeleton and selected bones. The fresh skeleton, exclusive of ligaments, weighed 10,017 gm., equivalent to 14.84 per cent of the total body weight. Volkmann's subject (see above), weighing 62.5 kilos, possessed a fresh skeleton weighing 10,164 gm., or 16.3 per cent of the body weight. Whether this skeletal weight included ligaments is not known. Scammon states: "Together, the bony and cartilaginous skeleton forms from 15 to 20 per cent of the total body weight at birth. Its post-natal growth proceeds parri passu with that of the body as a whole and, so far as our rather meagre statistics show, the proportions between the skeleton and body weight which exist at birth remain practically unchanged. The absolute post-natal increase in the weight of the skeleton, like that of the body as a whole, is roughly twenty-fold" (19). In a later publication from Scammon's laboratory, Wilmer (20) reports that the fresh ligamentous skeleton accounts for 17.60 per cent of the body weight of the new-born as well as of the adult.

The composition of the skeleton of our subject, and of the tibia, ulna, and rib analyzed separately, is summarized in Table II.[3] It will be noted that the different bones differed quite definitely in chemical composition, as Weakley and Dustman (21) found to be true for the different skeletal parts of the lower animals. This means that the composition of the skeleton cannot be estimated from that of an individual bone, as Nicholls and Nimalasuriya (6) have done, and probably others also. It is obvious that the fat and water contents of different bones vary widely, and probably that different skeletons equally well calcified may differ greatly in these respects. Comparisons of the composition of skeletal parts from different bodies, therefore, are best made on the dry, fat-free basis.

According to Huggins (22), "normal mature bone contains on the average somewhat less than half its weight of water and anything up to 25 per cent fat," these constituents varying within wide limits, depending upon the specific bone, the age, state of nutrition, and species. "The composition of the dry, fat-free matter is more uniform, being roughly 30 to 40 per cent organic and the remainder inorganic material." The bones analyzed in this experiment all fall within these very general specifications, except that some were somewhat drier and the tibia was considerably richer in fat. The skeleton of Volkmann's man contained 22.11 per cent ash as compared with 28.91 per cent for our specimen. Wolff and Kerr (23) analyzed

[3] Other measurements on the ulna, tibia, and rib, respectively, are as follows: maximum length, in cm., 27.85, 40.7, 30.3; minimum diameter, in cm., 1.15, 2.25, 0.55; density by water displacement (determined on the fresh intact bone with all adhering tissue removed), 1.32, 1.31, 1.50.

several bones from a case of chronic fluoride poisoning, and reported the results on the dry, fat-free (alcohol and ether-extracted) bone. The total ash on this basis was 65.01, 65.51, and 66.84 per cent for the tibia, ulna, and sixth rib, respectively, as compared with 66.34, 64.00, and 57.54 for our specimen, the last value relating to the ninth rather than the sixth rib. The percentages of calcium in the ash of the fluorotic bones were abnormally high, being 45.10, 44.68, and 43.75, respectively, and the phosphorus contents were somewhat high, also, *i.e.*, 17.60, 17.81, and 17.22.

Radasch (24) determined the content of organic matter in ether-extracted compact bone from postmortem subjects. This material contained no periosteum, cancellous tissue, or marrow. For subjects from 20 to 60 years of age, the average content of organic matter for femur, tibia, and fibula was 34.46 per cent, the content of inorganic matter thus being 65.54

TABLE III

Per Cent Composition of Bone Ash

Bone	Calcium content	Phosphorus content	Ratio, Ca:P	Authority
Humerus	36.67	16.01	2.29:1	Gabriel (25)
Ribs	38.80	17.41	2.24:1	Gassmann (26)
	37.09	16.95	2.19:1	Loll (27)
Humerus	36.31	15.43	2.35:1	Funaoka and Shirakawa (28)
Various bones	35.09	15.16	2.31:1	Klement (29)
Tibia	37.96	16.82	2.26:1	This experiment
Ulna	39.37	17.06	2.31:1	" "
Rib	38.97	16.60	2.35:1	" "
Entire skeleton	38.12	16.72	2.28:1	" "

per cent. The tibia described in Table II, including all parts of the bone, contained 66.34 per cent ash on the dry, fat-free basis.

Table III contains values published in the literature on the calcium and phosphorus content of the ash of human bones, in comparison with those secured on bones analyzed in this experiment.

From a consideration of all of these comparisons of measurements secured on the cadaver of this experiment with those of similar material reported in the literature, there is no reason to suspect that the specimen at our disposal was malnourished in any respect. It must be admitted, however, that comparable material is small in amount and variable in significance.

Bearing on Biochemistry of Growth—Growth consists of the deposition within the body of the young animal of organic and inorganic substances essential to protoplasmic functioning or to the development of an architectural structure determined by its hereditary background. These substances are derived from the food supply, either directly or by metabolic transformation, and they are deposited within the tissue cells or in the intercellular material, the former process during extrauterine growth involving mainly increase in cell size rather than increase in cell number. The chemical reactions involved in this enlargement of a young organism according to a predetermined pattern, and the factors involved in the termination of the process when a predetermined adult size is reached, are a fascinating field of biochemistry. But its practical aspects relate to the quantitative measurement of the day to day accretions of nitrogen (protein), energy, minerals, etc., since these accretions, when measured under appropriate experimental conditions, determine the requirements of net dietary nutrients for maximum growth.

Mitchell and Curzon (8) attempted to estimate the daily accretions of calcium in the case of the growing child on the basis of admittedly inadequate data. With the information now at hand on the composition of the adult human body, another attempt will be made in this section of the paper. However, in the absence of all direct information on the composition of the human body between birth, or shortly thereafter, and maturity, the attempt will represent more an illustration of method rather than the attainment of definitive values.

The growth data of Meredith (30) for boys from 5 to 17 years,[4] inclusive, extrapolated at both ends of the growth period to conform to a birth weight of 3.49 kilos (31) and a weight at 20 years of 67.0 kilos, were found to be satisfactorily described by a fifth degree equation, $W = 3.49 + 7.7876t - 1.6148t^2 + 0.1799t^3 - 0.007863t^4 + 0.0001165t^5$, in which W is the body weight in kilos and t is the age in years. The maximum deviation of weights estimated by this equation from the observed data is −7.5 per cent at 1 year of age and all other deviations are less than 5 per cent (see Table IV). Differentiation of this equation will give the rate of growth in kilos per year at any age t.

The changing calcium content of the growing boy's body was expressed by a fourth degree equation, based upon the assumption (*a*) that the calcium content at birth is 0.8 per cent (32), (*b*) that that in the adult is 1.6 per cent, and (*c*) that the change from the infantile to the adult percentage occurs progressively throughout growth, but more rapidly when growth is more rapid. The equation thus derived follows: $W = 28 + 86.828t - 16.$-

[4] In this article, Meredith reviews the evidence in the literature and adds evidence of his own concerning secular changes in the weight and height of children. He concludes: "Altogether it appears to be reliably established that the average stature and weight of white children living in the United States and enrolled at public or private schools has increased during the last half century." It is a relief to find concrete evidence that changing food habits in this country are not undermining health, contrary to the belief frequently expressed in official circles, based upon less specific evidence and an inept use of experimental and statistical data.

$5105t^2 + 1.5625t^3 - 0.04114t^5$, in which W is the weight of calcium in gm. in the child's body and t the age in years. Differentiation of this equation will give the rate of accretion of calcium in gm. per year. Table IV con-

TABLE IV

Growth of Boys in Body Weight and Calcium Content

Age	Body weight			Calcium content‡	Daily accretion			Calcium content of gains in weight
	Observed*	Calculated†	Deviation		In body weight§	In calcium‖		
						Total	Per kilo body weight	
yrs.	*kg.*	*kg.*	*per cent*	*gm.*	*gm.*	*mg.*	*mg.*	*per cent*
0	3.49	3.49	0	28				
1	10.6	9.84	−7.5	100	13.9	160	16.3	1.15
2	13.7	13.9	1.5	147	8.9	105	7.6	1.18
3	16.0	16.6	3.8	179	5.9	70	4.2	1.19
4	17.6	18.4	4.5	201	4.5	53	2.9	1.18
5	19.1	20.0	4.2	219	4.3	50	2.5	1.16
6	22.0	21.7	−1.4	239	4.9	60	2.8	1.22
7	24.4	23.7	−2.8	264	6.1	79	3.3	1.30
8	27.5	26.2	−4.7	297	7.6	105	4.0	1.38
9	30.4	29.2	−3.9	341	9.1	135	4.6	1.48
10	33.3	32.8	−1.5	396	10.5	167	5.1	1.59
11	36.5	36.8	1.1	463	11.6	197	5.4	1.70
12	39.5	41.2	4.3	539	12.3	223	5.4	1.81
13	44.0	45.8	4.9	624	12.5	242	5.3	1.94
14	49.9	50.3	0.8	715	12.1	251	5.0	2.07
15	55.0	54.6	−0.7	806	11.3	249	4.6	2.20
16	59.6	58.5	−1.8	894	9.9	231	3.9	2.33
17	62.6	61.8	−1.3	973	8.8	196	3.2	2.23
18	64.5	64.4	−0.2	1035	6.1	141	2.2	2.31
19	66.0	66.3	0.5	1073	3.9	63	0.95	1.62
20	67.0	67.3	0.4	1078	1.8			

* Growth data of Meredith (30) supplemented for ages less than 5 years and more than 17 by the earlier data of Bayley and Davis (33) and by data selected by Brody (34).

† Calculated from the equation, $W = 3.49 + 7.7876t - 1.6148t^2 + 0.1799t^3 - 0.007863t^4 + 0.0001165t^5$, in which W = body weight in kilos and t = age in years.

‡ Calculated from the equation, $W = 28 + 86.828t - 16.5105t^2 + 1.5625t^3 - 0.04114t^4$, in which W = body calcium in gm. and t = age in years.

§ Obtained by differentiation of equation given in † foot-note.

‖ Obtained by differentiation of equation given in ‡ foot-note.

tains the estimated rates of calcium accretion expressed in mg. per day and in mg. per kilo of body weight. The last column of Table IV contains the estimated calcium content of the daily accretions in body weight for the different ages considered. These values are quite in line with similar values obtained for rats, chickens, and lambs cited by Mitchell and Curzon ((8) Tables 4 and 5), taken from experiments in which animals were actually analyzed at different stages of growth.

The estimated accretions of calcium per day in the body of the growing male child listed in Table IV for boys of different ages from birth to 20 years are quite similar in absolute magnitude to the estimates of Shohl (9) obtained by an analogous method. Expressed per kilo of body weight, the values in Table IV are generally smaller because of a different age-weight relationship. Both sets of data, however, integrate to nearly the same total of 1.0 to 1.1 kilos of calcium at maturity.

The results of calcium balance experiments upon children at different stages of growth generally indicate higher daily accretions of calcium than those listed in Table IV. For example, Sherman and Lanford ((35) Table 8) have published average retentions of calcium for different age intervals, and all of them, except for the 10th to the 15th year, are considerably higher than the values in Table IV. However, they integrate at 15 years to a total, 1247 gm., larger than we have found in the adult body and equivalent to 2.3 per cent. They give also average calcium retentions compiled by Macy, probably from more recent data. This series of values integrates to a total of 1418 gm., equivalent to 2.0 per cent of the adult body weight. The calcium balances of children selected by Leitch (7) are much higher and lead to an estimate of 3.6 per cent of calcium in the adult.

The possible causes of the discrepancies between the two methods of estimating daily accretions of calcium by the growing child are discussed by Mitchell and Curzon (8). It seems fair to conclude that the gross errors of the balance method all operate to increase the estimated calcium retention. The difficulties in securing calcium balances in a growing child that represent growth requirements do not seem to be commonly realized. At any given time calcium may be retained in a bone either as a stage in its orderly development at a rate that has been unimpeded by the food supply, or as a recuperative process imposed upon normal bone growth by a prior period of inadequate food supply. The latter quota is not a legitimate part of a net requirement of calcium for bone growth, because it would not exist under conditions of continuous fully adequate nutrition, and its existence following a period of inadequate nutrition will terminate when recuperation is complete.

The way in which a bone grows would seem to confuse the interpretation of calcium balances, at least in short periods of observation. Maximow and Bloom (36), in discussing the internal reconstruction of growing bone, say: "Inside the gradually increasing mass of a growing bone, changes are constantly taking place throughout its entire period of development even to the adult stage. These consist of the formation of new lamellae by the osteoblasts and, at the same time, of destruction and digestion of the recently formed areas of bone tissue, the formation of other new layers, and so on."

The technical errors in a calcium balance study relate mainly to a complete collection of excreta. To the extent that excreta are lost, the calcium balance is fictitiously high. No attention is ordinarily paid to the dermal loss of calcium. Bryant and Talbert (37) found calcium as a normal constituent of sweat. They reported the presence of from 5 to 10 mg. of calcium per 100 cc. of sweat, in 83 samples analyzed. Freyberg and Grant (38) were unable to detect calcium in the skin secretions of normal humans when sweating is avoided. However, in our laboratory[5] we have found calcium in dermal excretions under comfortable environmental conditions, equivalent to a loss of 4 to 5 mg. per hour over the entire body. Sweat always contains calcium but in highly variable concentrations from less than 1 mg. per cent to 8 or 9. Under conditions of profuse sweating, the dermal loss of calcium may range from 10 to 20 mg. per hour in normal adults. The extent of this loss in children should be studied.

The method for calcium illustrated above may be extended to protein, energy, and phosphorus. Terroine (39) has applied essentially the same method to a determination of the net protein requirements of the child. Obviously, in any consideration of nutritive requirements estimated by this or any other method, the great variability of individuals must be realized and the adaptation of the individual to a restricted food supply, as illustrated by Nicholls and Nimalasuriya (6) for calcium, cannot be neglected. Such estimated requirements are useful as guides in child feeding, but they are of little value as "yardsticks of good nutrition." It is a statistical absurdity to judge the nutritive status of large communities, even an entire population of 136 million people, by average experimental results obtained upon a mere handful of subjects, whose variation is of the order of 20 to 25 per cent.

SUMMARY

The chemical composition of the body of a normal adult human, 35 years of age, has been reported, with reference to moisture, ether extract, protein (N × 6.25), total ash, calcium, phosphorus, and gross energy. Individual analyses of the skeleton, musculature, skin, and many visceral organs are reported.

The data from this material have been considered in connection with requirements of calcium for growth on the reasonable assumption that the integration of calcium accretions during the growing period will equal the calcium content of the adult organism.

[5] Mitchell, H. H., and Hamilton, T. S., unpublished data.

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