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Chapter 3 Physiological data for reference man

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CHAPTER 3

PHYSIOLOGICAL DATA FOR REFERENCE MAN

A. INTRODUCTION

The scope of this chapter is to review those characteristics of man that relate directly or indirectly to intake, metabolism, and excretion of stable elements in man's environment. The rationale behind this approach for evaluation of intake and metabolism of radioactive nuclides has been outlined in the Introduction (p. 1). Significant differences of metabolism from those of the stable element are not expected for most isotopes of physiological importance (those of hydrogen being exceptional) when they reach the body in reasonable quantities and as food components. Long-lived nuclides in fallout from weapons testing or the natural radionuclides may be expected to approximate a state of equilibrium in the environment, and the stable element metabolism is appropriate. Also, because of the influence of the natural isotopes as carriers, many short-term exposures to radionuclides will follow a similar pattern of metabolism. At the same time it is important to remember that many other factors, such as the chemical and physical form and the presence or absence of other food components, can have significant effects. Where information of this kind is available, it should be applied to the specific problem in question.

In addition, since values are required for the overall intake of food, water, and air and for the appropriate metabolic levels for a Reference Man, data of this nature are also included. The physiological characteristics of Reference Man are designed to define a typical occupational individual and to indicate the variability about the "reference" value selected as well as differences due to age, sex, or particular habits.

In compiling data for a physiological Reference Man, a limitation was set that our "man" be of Western European or North American origin, habitat, and custom, i.e., caucasoid in type and culture. Most of the literature readily available to us is from Western European or North American sources, and with a few exceptions the values given relate to caucasoid man. Our coverage of the literature is not exhaustive; in so wide a field, the choice of sources must to some extent be personal. The values chosen appear to be reasonably "representative" of the relevant population, and further search of the literature has rarely changed the overall view. However, new information is appearing continually, and this account should not be taken as definitive.

This chapter is divided into two principal parts: sections B–N are intended to provide data for a physiological model of reference man (or woman or child), while section O relates to the metabolic balance of individual stable elements. It should be noted that because of the diversity of material, the information quoted is not always in equivalent terms; some information (e.g., in the section on food consumption) is available only on a *per caput* basis, whereas the model relates to adult Reference Man. This has led to some apparent discrepancy of values, specifically for the bulk elements in subsections of section O where model values for Reference Man have been proposed.

Wherever relevant information is available, an attempt is made to relate specific variables to age and sex; however, in many instances, values are reported for unspecified groups, and studies for infants and children are very few. Consequently, differences of metabolism due to age can be indicated only tentatively. For some rarely studied elements, values are few and often derived from investigation of a small number of subjects. On the other hand, some studies (especially surveys of family food consumption) have been made with significantly large representative populations. These diverse sources of data make the interrelation of values to predict metabolic balances unrealistic; however, the need to provide such models has over-ruled these reservations. At the same time, the reader should not forget the incompatibility of much of the original data.

Certain conventions have been followed throughout the text. Adult values refer to men or women >20 years, whereas Reference Man is between 20 and 30 years (p. 4 of the Introduction). Subjects older than 60 years are rarely included in reported studies unless specifically with reference to old age. Infant here refers to the first postnatal year; younger children are more than 1 and less than 8 years; children are 8–12 years (with the object of specifying a "reference" child at 10 years); older children are more than 12 years.

The intakes of elements in drinking water given in section O have been calculated from water composition on the basis of a consumption of 2 l/day unless specific sources of water intake are referenced. Intakes by inhalation have been calculated from air concentrations on the basis of the ICRP (ref. 278, p. 153) convention, i.e., 75% of inhaled air is "deposited" in the upper and lower respiratory passages unless specific estimates are reported. Urinary losses in sections G and O have been estimated from urine concentrations on the basis of a daily excretion of 1.4 l for a Reference Man unless specific daily excretion is reported (for appropriate values for children, see pp. 353–354). However, fecal losses in section O refer to reported daily or stool losses, without any attempt to standardize these to the fecal model (p. 353).

Within the subsections of section O, there is great variability in the quality of the data presented. Intake estimates are derived in two principal ways: (1) by dietary surveys of relatively large groups, or (2) by carefully controlled balance studies of a relatively few individuals. The first has the disadvantage that the age structure of the population is rarely recorded, that techniques of sampling are notoriously difficult and may be variable in different studies (e.g., family food consumption or family food purchase), that meals or snacks taken outside the household are not recorded (but may or may not be allowed for), and that single elements are rarely studied but are derived by calculation from standard tables of food composition not necessarily applicable to the situation in question. On the other hand, these estimates have the advantage that large populations can be studied, and the consumption *per caput* can be checked against national supplies of food components. The balance study has the obvious disadvantages that few individuals can be studied and that free chosen diets often show considerable idiosyncrasy of choice. The advantages are that age and sex are usually recorded, the whole food intake can be followed, and generally specific elements are measured by analysis of aliquots or duplicate meals. The two methods often provide widely different estimates of intake (ref. 218).

Since body weight, W, of females of age 15 years or over generally averages significantly less than that of males, it is likely that the intake of food also will show a sex difference. Data on intakes, when specific for sex, tend to confirm that such a difference does exist in an average sense, although the ranges of values reported for males and for females are quite large and overlap to a considerable extent. Data on intake of calcium has been plotted to illustrate this hypothesis. Reference intakes for males and females have been shown for other elements based on similar considerations, although the sex-specific data are usually not presented in detail.

Urinary excretion of elements is measured by analysis of samples usually of a relatively small number of individuals, although there have been studies on a population basis for a few elements. The extrapolation of values obtained for a urine sample to a daily excretion will lead to some error, and few sources relate the sample to daily creatinine excretion; where information is available on significant circadian fluctuations in urinary excretion, it is noted in the text. At least for those elements homeostatically controlled by the body, urinary concentrations will fall within a restricted range, especially for normal or typical diets, and this generally means more accurate analysis of the sample. Consequently, where incompatibility of intake and excretion data was found for the model, more reliance has been placed on urinary analyses (where these are adequate). However, a recent interlaboratory study of trace element (and even major electrolyte) analysis of urine samples indicated large variations, even when a common technique was employed (ref. 284).

Estimates of excretion of elements in feces were derived from direct chemical analyses, not by difference of intake and urinary excretion, but the data are limited. The great variability of concentrations, reflecting both variable intake and variable absorption, together with great variation in the frequency of defecation, means that the values in the literature generally show a very wide range. Most analyses reported refer to stool concentrations rather than to daily losses. Where possible, values are related to a specific level of intake.

To these sources of variation in all samples must be added the variability inherent in collating material provided by different investigators using different analytical procedures on different subgroups of the population selected. The possibility of variation due to differences of ethnic or regional groups should be considered whenever the model values derived here are used (ref. 580). In selecting model values from available data, an assumption was made that average daily input and average daily output are in balance.

It was decided that values for the intake and loss of elements for a Reference Man would be given to two significant figures (even though the data might support greater or lesser accuracy; see Introduction, p. 5) and that the metabolism of each element should be considered as an approximate balance unless any net loss or gain of the element in tissue with age is reported. The balance values are meant to relate to a Reference (70-kg) Man unless otherwise indicated, and corrections based on differences of weight, metabolism, or total food intake should be applied if extrapolation to a reference woman or child is considered. Exceptions are made in the text for major elements iron, magnesium, and calcium. Where specific information is available in the literature for women or children of different ages, this may be preferred.

It cannot be stated too firmly that the model values were chosen by reference to the quoted literature, but they represent an entirely hypothetical Reference Man not to be related to any particular individual, population, or environmental situation. They do not refer to a real situation nor do they represent the degree of analytical or sampling accuracy of the values reported from the literature. The text, on the other hand, does indicate the observed range of variability of real individuals or populations. For a very few elements, mean values relating element intake to age have been plotted graphically to indicate a restricted range of variation. The curves drawn by eye in these figures represent suggested model values for age, based on the information quoted in the text and by additional references quoted.

The following compilation of data includes a little information on minor sources of loss which might be considered irrelevant to our task (sections M and N). While sweat (section L) is of obvious importance in an account of mineral balance and secretion of milk (section K) only during relatively short periods in the life span, other secretions can have little significance in the total balance. However, since these may be used or considered as bioassay materials, their elemental composition is of some interest. Composition of hair and nails may be found in Table 108.

B. ENERGY EXPENDITURE

Food and oxygen are consumed in proportion to energy requirements and are influenced by sex, size, age, environmental temperature, and activity. Data for calculation of calorie requirements, oxygen consumption, and carbon dioxide production are given below.

1. STANDARD ENERGY EXPENDITURE

Reference Man is assumed to live in a temperate climate (10–20°C) and to weigh 70 kg (Reference Woman, 58 kg). Reference standards for energy requirements of a Man of 65 kg (Woman, 55 kg) living in a temperate zone (mean annual temperature 10°C) have been established by the Food and Agriculture Organization (FAO; ref. 179). (Refs. 151, p. 118; 179; 180.)

Reference Man and Woman, as here defined, are larger than FAO Man and Woman, and they also live at a higher environmental temperature. Corrections for increased weight and temperature tend to cancel each other, and the differences are insignificant in relation to the variation in measured energy expenditures. However, recent estimates of energy expenditures of men and women in the United States indicate about 2800 kcal/day (22–35 years, 70 kg) and 2000 kcal/day (22–35 years, 58 kg), respectively (ref. 560). The setting of a lower level of energy expenditure continues a trend begun earlier (ref. 206). The allocation of energy expenditures to various daily activities would remain similar to that of FAO Man and Woman which are given in Tables 112 and 113. The values chosen for ICRP Reference Man and Woman represent a compromise between these values.

Energy expenditure for reference man

Adult man	Adult woman	Child (10 y)
3000 kcal/day	2100 kcal/day	2000 kcal/day

TABLE 112. ENERGY EXPENDITURE OF ADULT FAO MAN
(ref. 151, p. 119)

	kcal/d	kcal/d
8 h light working activities: mostly standing (overall rate, 2.5 kcal/min)		1200
8 h nonoccupational activities:		
1 h washing, dressing, etc., at 3 kcal/min	180	
1.5 h walking at about 6 km/h at 5.3 kcal/min	480	
4 h sitting activities at 1.54 kcal/min	370	
1.5 h active recreations and/or domestic work at 5.2 kcal/min	470	1500
8 h rest in bed at BMR[a]		500
Total		3200

[a] Basal metabolic rate, the minimal rate of heat production in a fasting, supine individual in a room temperature of about 20°C.

TABLE 113. ENERGY EXPENDITURE OF ADULT FAO WOMAN
(ref. 151, p. 120)

	kcal/d	kcal/d
8 h light working activities in the home or in industry: mostly standing (overall rate, 1.83 kcal/min)		880
8 h nonoccupational activities:		
1 h washing, dressing, etc., at 2.5 kcal/min	150	
1 h walking at about 5 km/h at 3.6 kcal/min	220	
5 h sitting activities at 1.41 kcal/min	420	
1 h active recreation and/or heavier domestic work at 3.5 kcal/min	210	1000
8 h rest in bed at BMR		420
Total		2300

2. RELATION OF ENERGY EXPENDITURE TO AGE AND SEX

Energy expenditure increases with body size to about 20 years and then decreases from the Reference Man value of 3000 kcal/day by 3% for each decade to 45 years, by 7.5% for each decade from 45 to 65 years, and by 10% from 65 to 75 years (refs. 151; 179). It is closely linked with W at any specified age. The date for energy expenditure at various ages in Table 114 have been collated from ref. 151 using W for Reference Man and Woman as 70 kg and 58 kg, respectively; for infant, 3.5 kg; and for child of 3 years, 14.5 kg. Little information is available for infants other than in the resting state. Data for energy expenditure in relation to age and sex are presented in Table 115.

TABLE 114. ENERGY EXPENDITURE FOR DIFFERENT AGE GROUPS, RESTING,[a] SITTING, OR STANDING QUIETLY

Age (y)	Resting[a] (kcal/min)		Sitting (kcal/min)		Standing (kcal/min)	
	Male	Female	Male	Female	Male	Female
Infant	0.119					
1–5	0.377					
6–8	0.70	0.60	1.2		1.7	
9–11	0.79	0.74	1.0	1.2	2.2	2.0
12–19			1.47	1.25	1.70	1.40
20–39	1.21	0.95	1.49	1.21	1.88	1.44
40–65			1.48	1.13	1.84	1.29
65+			1.39	1.15	1.53	1.17

[a] Resting energy expenditure is that of a supine individual at a room temperature of about 20°C. It is a minimal metabolic state like BMR but differs in that it is independent of previous nutritional history.

TABLE 115. DAILY ENERGY EXPENDITURE IN RELATION TO AGE AND SEX (adapted from ref. 179)

Age (y)	Energy expenditure (kcal/d)		O_2 consumed (l/d)		CO_2 produced (l/d)	
	Males	Females	Males	Females	Males	Females
< 1	1100		230		180	
1–3	1300		260		210	
4–6	1700		340		280	
7–9	2100		420		350	
10–12	2500	2400	500	480	410	390
13–15	3100	2600	620	520	510	430
16–19	3600	2400	720	480	590	400
20–29	3200	2300	640	460	530	380
30–39	3100	2200	630	450	520	370
40–49	3000	2200	620	430	510	350
50–59	2800	2000	560	400	460	330
60–69	2500	1800	510	370	420	300
> 70	2200	1600	440	320	360	260

For Reference Man's daily energy expenditure of 3000 kcal, he must inhale 620 l of oxygen (STP†) and exhale 510 l of carbon dioxide. These are equivalent to the gram amounts shown for reference man (p. 340).

Inhalation data for Reference Man

	Adult man	Adult woman	Child (10 y)
Oxygen inhaled (g/day)	920	640	600
Carbon dioxide exhaled (g/day)	1000	700	660

† Standard temperature (0°C) and pressure (760 mm Hg).

Both resting and basal metabolism may be defined in terms of W, but both also vary with age. Data on resting metabolism for various ages are presented in Table 116. (For resting metabolism, see ref. 151, p. 98; for basal metabolism, see ref. 140, p. 630).

TABLE 116. CHANGE OF RATE OF RESTING METABOLISM WITH AGE

(derived from data in ref. 151, p. 98)

Subject	Body wt., W (kg)	Metabolic rate (cal/min-kg W)	Metabolism (kcal/24 h)
Man	65	17	1590
Boy	60	19	1640
Child	30	26	1120
Infant (newborn)	3	34	146

Metabolic rate for Reference Man

Adult man	Adult woman	Child (10 y)	Infant (1 y)
17 cal/min-kg W	**16 cal/min-kg W**	**25 cal/min-kg W**	**35 cal/min-kg W**

3. RELATION OF ENERGY EXPENDITURE TO OCCUPATION

Occupational activities may be graded according to the calories expended in their execution. The customary categories are listed in Table 117.

TABLE 117. GRADING OF INDUSTRIAL WORK

(calculated from ref. 151, p. 47)

	Gross energy expenditure	
	Men (kcal/min)	Women (kcal/min)
Light	2.2–5.3	1.6–3.6
Moderate	5.4–8.0	3.7–5.7
Heavy	8.1–11	5.8–7.8
Very heavy	11–13	7.9–9.9
Unduly heavy	14–	10–

Occupational activities classed as "light" are office work, most light industry, laboratory work, most hospital work, and most housework. "Moderate" activities include some housework, hospital work, and light industry. Occupations calling for consistent heavy expenditure are rare-commercial fishing, foundry work, face-work in mines, and ambulant postal delivery. Studies of groups of subjects engaged in different activities suggest that individuals will not depart from the mean by more than about $\pm 30\%$. (Ref. 151, pp. 115, 116.)

4. RELATION OF ENERGY EXPENDITURE TO OXYGEN CONSUMPTION

Energy expended will be replaced by food, requiring appropriate amounts of oxygen for combustion. In general,

$$\text{Energy (kcal)} = 3.78 \times (\text{liters } O_2 \text{ used}) + 1.16 \times (\text{liters } CO_2 \text{ produced}) - 2.98 \times (\text{urinary N, g}) \text{ (ref. 151, p. 17)}$$
$$= 3100 \text{ for 70-kg man excreting 15 g N.}$$

5. ADJUSTMENT OF BASAL METABOLISM FOR BODY SIZE

In general,

$$\text{Energy (kcal/d)} = 152 \times W^{0.73} \text{ (males)} = 123.4 \times W^{0.73} \text{ (females)},$$

where W is total body weight in kg, or

$$\text{Energy (kcal/d)} = 66.5 + 13.8\text{ W} + 5.0\text{ L} - 6.8\text{ A (males)}$$
$$= 65.5 + 9.6\text{ W} + 1.8\text{ L} - 4.7\text{ A (females)},$$

where W is in kg, L is height in cm, and A is age in years (ref. 231, p. 227).

Tables for correcting calorie consumption (basal metabolism) to weight, height, and surface area (at all ages) are given in Geigy, *Scientific Tables* (ref. 140, pp. 629–31).

Energy expenditure will vary with the proportions of lean body mass (LBM) and fat in the body as well as with gross body size. In Table 118 is given a simple account of such changes in resting metabolism (refs. 10, p. 344; 151, p. 31).

6. ADJUSTMENT FOR ENVIRONMENTAL TEMPERATURE

Effects of climatic conditions are very difficult to assess since activity, clothing, and resting metabolism may all vary with change in climate. In general, from a mean standard of 10°C, energy expenditure is decreased 5% for every increase of 10°C and increased 3% for every decrease of 10°C (ref. 179). Environmental temperature selected here as representative for reference man is 15–20°C.

TABLE 118. RESTING[a] RATE OF ENERGY EXPENDITURE OF ADULTS

Men	Women	Fat (% W)	Total body wt. (kg) 45	50	55	60 (kcal/min)	65	70	75	80
Thin		5		0.99	1.06	1.12	1.19	1.26	1.32	1.39
Average		10		0.94	1.01	1.08	1.14	1.21	1.28	1.34
Plump	Thin	15	0.82	0.89	0.96	1.03	1.09	1.16	1.23	1.30
Fat	Average	20	0.78	0.84	0.91	0.98	1.05	1.11	1.18	1.25
	Plump	25		0.80	0.86	0.93	1.00	1.07	1.13	1.20
	Fat	30			0.81	0.88	0.95	1.02	1.08	1.15

Continued

TABLE 118—*Continued*

RESTING[a] OXYGEN CONSUMPTION OF ADULTS

Men	Women	Fat (% W)	Total body wt. (kg) 45	50	55	60	65	70	75	80
			(O_2ml/min)							
Thin		5		206	220	234	248	262	276	290
Average		10		196	210	224	238	252	266	280
Plump	Thin	15	172	186	200	214	228	242	256	270
Fat	Average	20	162	176	190	204	218	232	246	260
	Plump	25		166	180	194	208	222	236	250
	Fat	30			170	184	198	212	226	240

[a] See footnote to Table 114 (p. 340).

7. EFFECT OF PREGNANCY AND LACTATION

During the total period of pregnancy, the additional kcal requirement may be subdivided as follows (ref. 151, p. 96):

Fetus	7,500 kcal/266 d
Placenta and maternal tissues	7,500 kcal/266 d
Additional fat (4–5 kg)	40,000 kcal/266 d
Increased energy metabolism	25,000 kcal/266 d
Total	80,000 kcal/266 d

This amount of calories will be required in addition to normal requirements, provided that activity remains the same.

During lactation, a reasonable maintained average milk production is 850 ml/day (see p. 360). It is assumed generally that there is an additional calorie requirement of 1000 kcal/day during lactation or 180,000 kcal for a 6-month period.

C. RESPIRATORY STANDARDS

The characteristics of respiration are described by primary volumes of respiration and the capacities of the lung. Within mammalian species, lung volumes generally are proportional to body weights (ref. 540). In man, lung volumes increase in relation to increase in W and are correlated with body surface area. Tidal volume is, approximately, a constant fraction of lung volume.

Primary volumes (ref. 106, p. 9):

1. *Tidal volume* (TV) or depth of breathing is the volume of gas inspired or expired during each respiratory cycle.
2. *Inspiratory reserve volume* (IRV) is the maximal amount of gas that can be inspired from the end-inspiratory position.
3. *Expiratory reserve volume* (ERV) is the maximal volume of gas that can be expired from the end-expiratory level.

4. *Residual volume* (RV) is the volume of gas remaining in the lungs at the end of a maximal expiration.

Capacities (*ref. 106, p. 9*):

1. *Total lung capacity* (TLC) is the amount of gas contained in the lung at the end of a maximal inspiration.
2. *Vital capacity* (VC) is the maximal volume of gas that can be expelled from the lungs by forceful effort after a maximal inspiration.
3. *Inspiratory capacity* (IC) is the maximal volume of gas that can be inspired from the resting expiratory level.
4. *Functional residual capacity* (FRC) is the volume of gas remaining in the lungs at the resting expiratory level.

The relation between the primary volumes and capacities is illustrated in Fig. 66 (ref. 11, p. 27).

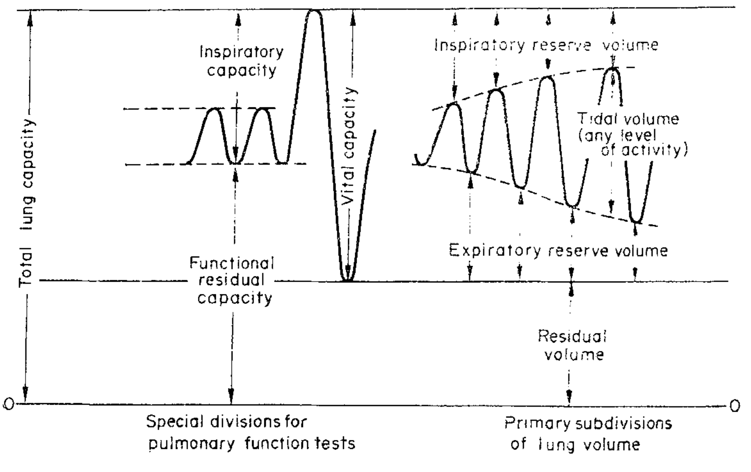

FIG. 66. Subdivisions of lung volume (ref. 10a, p. 35.)

1. LUNG CAPACITIES

In the adult, total lung capacity declines with age; vital capacity declines with age; functional residual capacity is unaltered or increases with age; and dead space† (VD) increases slightly with age (Table 119 and Fig. 67; ref. 134, p. 58).

Vital capacity is dependent on height, age, and sex.

Males: VC (ml, BTPS‡) $= (27.63 - 0.112 \times A) \times L$.
Females: VC (ml, BTPS‡) $= (21.78 - 0.101 \times A) \times L$.

† Anatomical dead space is the volume of airways down to where the gas concentration changes. No respiratory exchange takes place in this region. This volume constitutes the nose, nasopharynx, trachea, and tracheobronchial tree down to the respiratory bronchioles.

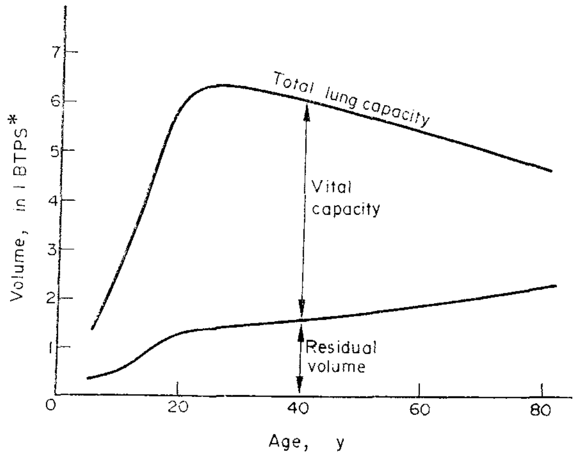

FIG. 67. Total lung capacity, vital capacity, and residual volume as a function of age for subjects of average build. (Reproduced from Dejours, ref. 134, p. 58.)

TABLE 119. RELATION BETWEEN AGE, BODY SIZE, AND LUNG CAPACITY

Subject	Age (y)	Total body Height (cm)	Total body wt. (kg)	Total body SA (m^2)	TLC (l)	FRC (l)	VC (l)	VD (ml)
Newborn	0	51	3.4	0.22	0.16	0.09 (0.06–0.11)	0.15	5
Infant	1	75	10	0.44				
Child	10	140	33	1.1	3.0 (2.4–3.4)	1.1 (0.8–1.3)	2.2 (2.0–2.7)	60
Woman	20–30	163	58	1.6	4.4 (3.9–5.4)	1.8 (1.5–2.1)	3.3 (2.3–4.1)	130
Man	20–30	175	70	1.8	5.6 (3.7–7.5)	2.2 (1.3–3.1)	4.3 (2.7–6.0)	160

(A in years, L in cm) (ref. 134, p. 58). Other formulae have been proposed for relating capacities or volumes to body size or weight (e.g., ref. 106, pp. 325–8). Similar calculations can be made for children (refs. 11, pp. 31–39; 13; 40; 106, p, 327; 158, p. 75; 246. p. 84; 251; 290, pp. 91–112; 335; 336; 397).

However, the vital capacity decreases when an individual ascends to higher altitudes, but this effect is transient. After a few days, the vital capacity approximates the individual's normal value (ref. 4, pp. 388–9).

Respiratory capacities for Reference Man

	Adult man	Adult woman
Total lung capacity (l)	**5.6**	**4.4**
Functional residual capacity (l)	**2.2**	**1.8**
Vital capacity (l)	**4.3**	**3.3**
Dead space (ml)	**160**	**130**

* Body temperature and pressure, saturated.

2. LUNG VOLUME AND RESPIRATION

The respiratory volume, or ventilatory flow (V), or minute volume ($\mathring{V}$), is a product of tidal volume (TV) and frequency (f). During exercise, both f and TV are increased. Ventilation also increases at high altitude (ref. 134, p. 53). Respiratory rate increases 5–6 per min for each °C rise in body temperature (ref. 105, p. 330). Table 120 summarizes changes in frequency and tidal volume for individuals of different age and different activities. Since values in the literature are often related to the one dimension of body size, an attempt to interrelate these has been made in this table by referring to the standard weight for the dimension quoted. Tidal volume (TV) varies even when the individual is at rest, but during activity, it varies more significantly (see Table 120). Frequency of respiration (f) also varies with degree of exertion (see Table 120).

While a number of studies relate minute volumes and other respiratory values to activity for adults (refs. 10, pp. 355–61; 11, p. 47; 105; 217; 426; 488; and Table 120), there is little information relating the effects of activity on lung function for children. For infants, almost all measurements appear to have been made during the resting state. In a few instances a maximal inspiration (during crying) has been recorded as "vital capacity" (e.g., 160–180 ml; ref. 490, pp. 75–76). Crying in infants is marked by an increase in minute volume (by a factor of about three) and usually in rate which ranges from 40 to 114 per min with a mean of 68 per min (ref. 136, p. 123). Values for air breathed during the resting state in 1-year-old infants are about 2.2 m^3/day or 1.53 l/min (refs. 17; 298; 309; 310). Estimates of the total daily inhalation for active infants, based on doubling of resting values, or on oxygen requirement, or on calorie consumption (ref. 386), suggest about 4.7 m^3/day or 3.26 l/min.

From section B (p. 338) in which the daily activities of Reference Man and Woman are seen to include approximately 8 h resting and 16 h light activities, the reference values (see p. 338) can be derived using the reference values of minute volume (see p. 346) and frequency for resting and light activity based on the data in Table 120. Alternate values for liters of air breathed each day for a man (from data in Table 120) could total 3.1×10^4 l/day, about 40% higher than the reference value chosen.

Minute volume for Reference Man

	Adult man	Adult woman	Child (10 y)	Infant (1 y)	Newborn
Resting (l/min)	7.5	6.0	4.8	1.5	0.5
Light activity (l/min)	20.0	19.0	13.0	4.2	1.5

Liters of air breathed for Reference Man

	Adult man	Adult woman	Child (10 y)	Infant (1 y)	Newborn
8 h working "light activity"	9,600†	9,100‡	6,240§	2,500‖ (10 h)	90¶ (1 h)
8 h nonoccupational activity	9,600†	9,100‡	6,240§		
8 h resting	3,600†	2,900‡	2,300§	1,300‖ (14 h)	690¶ (23 h)
Total	2.3×10^4	2.1×10^4	1.5×10^4	0.38×10^4	0.08×10^4
% of total air breathed at work	42	43			

† Line 3, Table 120. ‡ Line 6, Table 120. § Line 11, Table 120. ‖ Line 12, Table 120. ¶ Line 15, Table 120.

TABLE 120. SELECTED LUNG VENTILATION VALUES AT DIFFERENT LEVELS OF ACTIVITY AS A FUNCTION OF AGE

Col.	1	2	3			4			5			6			7
			Resting			Light activity			Heavy work			Maximal work during exercise			
Line	Subject	W (kg)	f	VT	$\mathring{V}$	f	VT	$\mathring{V}$	f	VT	$\mathring{V}$	f	VT	$\mathring{V}$	Refs.
	Adult														
1	Man	68.5	12	750	7.4	17	1670	29	21	2030	43				9, p. 220; 11, p. 41
2	1.7 m^2 SA		12	500	6										106, p. 323
3	30 y; 170 cm L		15	500	7.5	16	1250	20							378, p. 204
4	20–33 y	70.4										40	3050	111	10a, p. 82
5	Woman	54	12	340	4.5	19	860	16	30	880	25				9, p. 220; 11, p. 41
6	30 y; 160 cm L		15	400	6	20	940	19							378, p. 204
7	20–25 y; 165.8 cm L	60.3										46	2100	90	10a, p. 83
8	Pregnant (8th mo)		16	650	10										11, p. 40
	Adolescent														
9	♂, 14–16 y		16	330	5.2										11, pp. 43–44
10	♂, 14–15 y	59.4										53	2520	113	10a, p. 82
11	♀, 14–16 y		15	300	4.5										11, pp. 43–44
12	♀, 14–15 y; 164.9 cm L	56										52	1870	88	10a, p. 83
	Children														
13	10 y; 140 cm L		16	300	4.8	24	600	14							378, p. 204
14	♂, 10–11 y	36.5										58	1330	71	10a, p. 82
15	♀, 10–11 y; 140.6 cm L	32.5										61	1050	61	10a, p. 83
16	♂, 4–6 y	20.8										70	600	40	10a, p. 82
17	♀, 4–6 y; 111.6 cm L	18.4										66	520	34	10a, p. 83
18	Infant, 1 y		30	48	1.4[a]										585a, p. 259
19	Newborn	2.5	34	15	0.5										114, p. 981; 115, p. 566; 490, p. 80; 507, p. 1084
20	20h–13 wk	2.5–5.3										68[b]	51[a][b]	3.5[b]	136, p. 123
21	9.6 h	3.6	25	21	0.5										11, p. 42
22	6.6 d	3.7	29	21	0.6										9, p. 220; 11, p. 42

Values in column 2 are body weights referable to the dimension quoted in column 1. f = frequency (breaths/min); VT = tidal volume (ml); $\mathring{V}$ = minute volume (l/min); SA = surface area.

[a] Calculated from $\mathring{V} = f \times VT$.

[b] Crying.

D. DAILY DIETARY INTAKE

Daily intake of the principal components of the diet can be estimated in various ways. Family or household surveys of food purchased or consumed are commonly used to calculate an intake *per caput*, but even when the age structure of the sampled population is known, it is difficult to relate this realistically to adult or other individual intakes. Studies of individual intakes in balance studies, on the other hand, have the disadvantage that widely based samples of a population are rarely studied.

1. CONSUMPTION BASED ON HOUSEHOLD SURVEYS

The following estimates of *per caput* consumption are based on national and supranational household surveys. That for the United Kingdom relates to food purchased; 10% is deducted for waste (ref. 363, p. 135), and the original data are given as ounces per week correct to two decimal places. That for the Communauté Européene relates to food consumed; no allowance is made for waste since values given refer to actual consumption; the original data are given as mean annual consumption (kg) with up to six digits quoted. That for the United States relates to food purchased; 15% is deducted for waste (ref. 383), and the original data are given to the nearest gram quantities as grams per day.

The values shown in Table 121 represent *per caput* consumption, not consumption of a Reference Man, and reference values are not for a dietary intake model derived from these sources, but rather from studies of the intake of principal food components (section E, p. 350). The values presented in section D (p. 349) are intended for the evaluation of some international differences in diet.

2. CONSUMPTION ESTIMATES FROM NATIONAL SUPPLIES

Estimates of *per caput* consumption may also be derived on the basis of national supplies and the size of the population. Such estimates may include, however, food materials not subsequently used for human consumption (e.g., fish used as fertilizer or pet food, flour used in industry, etc.), or it may wrongly estimate food grown in the household (garden produce). Such estimates are more easily obtained than those from household surveys and are available for a number of countries where the family or household consumption has not been studied. Table 122 gives estimates of consumption of principal food groups for a variety of geographical regions.

E. PRINCIPAL NUTRIENT CONTENT OF DIET

The estimates of nutrient intake, given in Table 123, are based on the data shown in Table 121 and corrected for waste as specified (p. 348). The estimates for water intake in food are derived by difference for United Kingdom and Communauté Européene data but by direct computation for United States data. In the latter case, the total water intake in food includes 542 g from milk and 62 g from "soft" drinks and coffee, but it does not include an allowance for tap water or other water-based drinks. These are *per caput* estimates without reference to age.

TABLE 121. BRITISH, EUROPEAN, AND UNITED STATES DIETARY INTAKE

Food groups	Consumption *per caput* (g/d)		
	UK 1962–5 (refs. 360; 361; 363)	CEE 1963–5 (ref. 124)	USA[a] 1955 (ref. 557)
Milk[b] (as liquid)	382	287	508
Cheese	12	21	19
Meat + products	137	118	206
Fish + sea food	21	22	22
Eggs	34	21	47
Fats	44	63	49
Sugar + preserves	77	57	69
Potatoes	202	196	103
Other vegetables	118	180	202
Fruit	108	114	184
Cereals	246	346	207
Total	1381	1425	1611

[a] A more recent survey of household consumption in the United States (ref. 560) for spring 1965 indicates a 10% decline in the consumption of milk products and fats, a 20% decline in flour and cereals (but 14% increase in bakery products), an increase of 10% in meats and poultry, a decline of less than 10% in sugar, and a decline of 15% in potato consumption as compared with the 1955 data.

[b] This includes milk and all milk products with the exception of cheese which is listed separately. In the United Kingdom in 1964 ~6% of the total milk intake was consumed as dried or canned milk (ref. 363); in the United States, ~5% in 1959–63 (ref. 558; family consumption estimates).

TABLE 122. PER CAPUT ESTIMATES OF FOOD SUPPLIES (G/DAY) BY GEOGRAPHICAL REGION (ref. 255, p. 68)

Food groups	Far East	Near East	Africa	Latin America	Europe	North America	Oceania
Cereals[a]	404	446	330	281	375	185	243
Starchy roots[b]	156	44	473	247	377	136	144
Sugar[c]	22	37	29	85	79	113	135
Pulses and nuts[d]	56	47	37	46	15	19	11
Vegetables and fruits[e]	128	398	215	313	316	516	386
Meat[f]	24	35	40	102	111	248	312
Eggs[g]	3	5	4	11	23	55	31
Fish[h]	27	12	16	18	38	26	22
Milk[i]	51	214	96	240	494	850	574
Fats and oils[j]	9	20	19	24	44	56	45

[a] In terms of flour and milled rice.
[b] Includes sweet potatoes, cassava, and other edible roots.
[c] Includes raw sugar; excludes syrups and honey.
[d] Includes cocoa-beans.
[e] In terms of fresh equivalent.
[f] Includes offal, poultry, and game expressed in terms of carcass weight, excluding slaughter fats.
[g] Fresh egg equivalent.
[h] Landed weight.
[i] Excludes butter; includes milk products as fresh milk equivalent.
[j] Pure fat content.

TABLE 123. PER CAPUT DAILY CONSUMPTION OF PRINCIPAL NUTRIENTS IN FOOD (G)

Constituent	UK (1964)	CEE (1963–5)	USA (1955)
Protein	68	79	99
Carbohydrate	300	320	302
Fat	104	99	130
Water	899	927	1188

Nutrient intakes in Table 123 were calculated from family food survey data (Table 121, p. 349) and reference to standard texts of food composition (ref. 349 for United Kingdom; ref. 585 for United States). Values for the diet of the Communauté Européene are given in ref. 124 and have been derived from the appropriate national sources for the eleven regions surveyed.

Estimates for protein, fat, and carbohydrate for reference man are based on studies of individual adult male food consumption with reference to a daily energy expenditure of 3000 kcal. Literature for individual intakes of men, women, and children (refs. 28; 57; 75; 130; 148; 150; 341; 353; 366; 377; 380; 432; 441; 583; 594; 620; 622) is listed and summarized in Figs. 68–70.

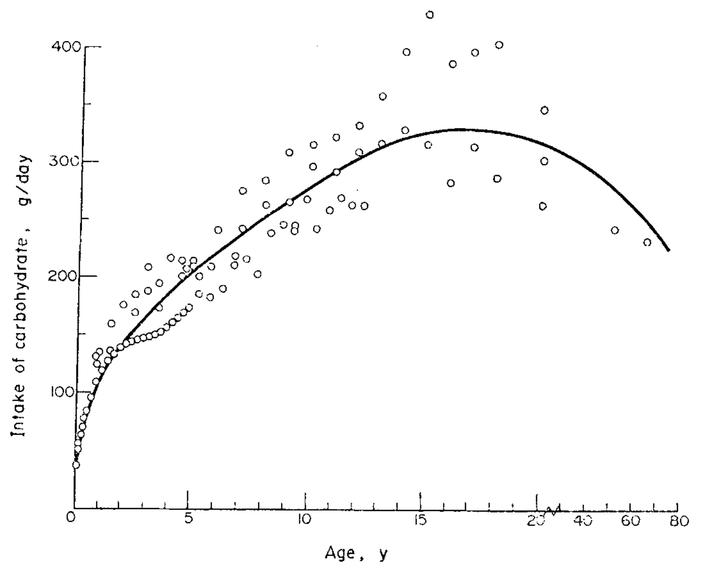

FIG. 68. Daily intake of carbohydrate as a function of age.

Similar estimates for adult woman and for different age groups might be obtained from Figs. 68–70 (refs. 28; 57; 75; 130; 148; 150; 341; 353; 366; 377; 380; 432; 441; 583; 594; 620; 622). However, this should be done with caution and only to indicate trends in consumption, since the individual points in the figures refer to relatively few individuals and since the compilation represents the work of different investigators. The lines drawn by eye in Figs. 68–70 are offered simply as guides in a purely pictorial sense. The model

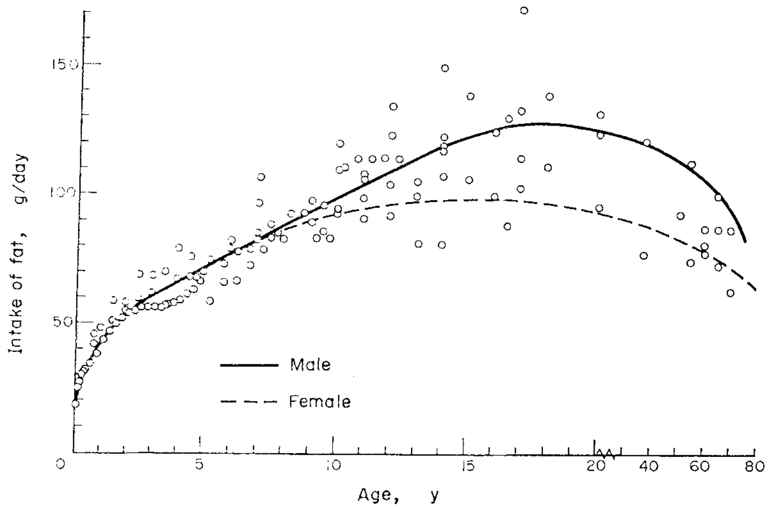

FIG. 69. Daily intake of fat as a function of age and sex.

intakes for Reference Woman have been derived by taking the Reference Woman's energy expenditure of 2100 kcal/day and assuming that her diet has the same components as those of man but differs only in quantity of intake. Reference values for a child (10 years) have been calculated on the basis of 2000 kcal/day.

Reference values for dietary intake of principal nutrients

	Adult man	Adult woman	Child (10 y)
Protein (g/day)	95	66	63
Carbohydrate (g/day)	390	270	260
Fat (g/day)	120	85	81

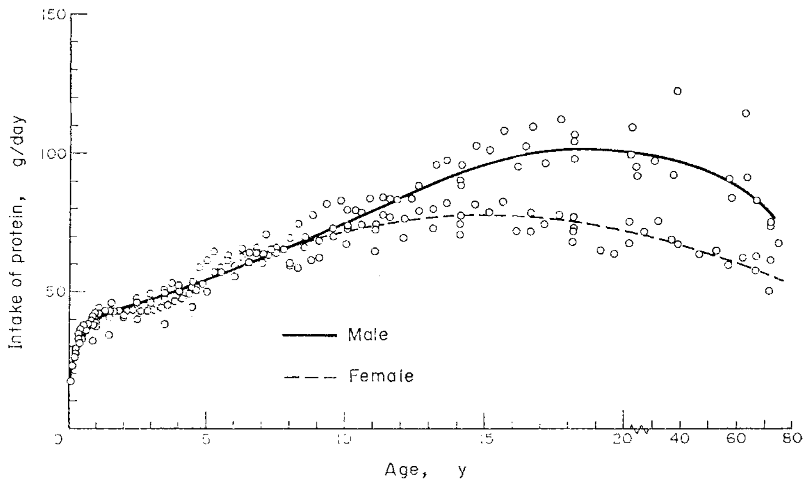

FIG. 70. Daily intake of protein as a function of age and sex.

1. MAJOR ELEMENTS IN THE DIET

The values in Table 124 for consumption of the major elements in the diet for the United Kingdom, European, and North American populations are calculated *per caput* on the basis of Table 123 (p. 350).

TABLE 124. PER CAPUT DAILY CONSUMPTION OF MAJOR ELEMENTS IN FOOD AND FLUIDS (G)

Element	UK	CEE	USA
Carbon	246	256	279
Hydrogen	325	329	362
Nitrogen	11	13	16
Oxygen	2484	2531	2750
Sulfur	1	1	1

The totals include hydrogen and oxygen derived from water in both food and fluids made from or solely of tap water (about 1700 ml/day).

Intake of major elements for reference man can be derived from the reference dietary intake of principal components of the diet (see p. 351). Carbohydrate is considered as starch, $(C_6H_{10}O_5)_x$, fat as glycerol tripalmitate, $(C_{15}H_{31}COO)_3C_3H_5$, and protein as 50% carbon, 7% hydrogen, and 20% oxygen.

Reference values for dietary intake of major elements

	Adult man	**Adult woman**	**Child (10 y)**
Carbon (g/day)	**300**	**210**	**200**
Hydrogen (g/day)	**350**	**245**	**230**
Nitrogen (g/day)	**16**	**13**	**10**
Oxygen (g/day)	**2600**	**1800**	**1700**
Sulfur (g/day)	**1**	**0.7**	**0.7**

F. DAILY FECAL LOSS

Good estimates of daily fecal loss of water, protein, carbohydrate, and fat are few in the literature. Many measurements have been made on stool composition, without reference to daily loss, and since the total lost each day is quite variable, it is difficult to adjust stool losses to daily losses.

The total weight of feces lost each day by adults ranges from 60 to 500 g (refs. 9, p. 190; 47, p. 348; 140, p. 526; 162, pp. 157–9; 399, p. 530; 529, p. 255; 549, p. 1684), with a mean value of about 150 g (ref. 47, p. 348). A value for Reference Man of 135 g has been suggested (ref. 162, p. 159). The weight varies with the diet but is maximal in vegetarian diets (refs. 83, p. 7; 140, p. 526). The wet weight of children's feces has been reported to range from 20 to 150 g/day (refs. 140, p. 526; 340, p. 123), and for infants' feces, ranges from 4 to 120 g/day (ref. 140, p. 526) and from 13 to 229 g/day (ref. 266, p. 215) have been reported. The dry weight of feces for adults is about 20% of the wet weight, but ranges from 4.4 to 28% (refs. 47, p. 348; 448, p. 108) and 4.6–38% (ref. 179, p. 17) have been reported. In children the dry weight is about 20% of the wet weight with a range of 16–26% (refs. 83; 340, p. 123). In infants ($n = 7$) water content was reported as 36 g/day with a range of 18–50 g/day (ref. 258, p. 219, table 3).

The ash of the majority of adult fecal samples was found to range from 0.8 to 3% wet weight (refs. 65a; 517a). The ash percent of wet weight estimated from the electrolyte composition agrees with these values (refs. 9, p. 190; 98; 140, p. 526). Due to the lack of data, the percentages for ash of wet weight for adults are used for all ages. (In ref. 258 (p. 219, table 3) the ash weight of infant feces has been reported, but the wet weight, the temperature of ashing, and the length of time required for ashing were not given.)

Feces are composed of water, ash, fat, protein, partially degraded celluloses, polysaccharides, bacterial debris, and other undigested food residues. The water content for adult feces is 70–80% of the total weight with a mixed diet but as high as 87% with a vegetarian diet and only 70% with a diet high in meat content (ref. 47, p. 348). A general value is $\sim$75% (refs. 9, p. 190; 140, p. 526). The fat content of feces varies considerably with fat intake, but even when on a fat-free diet there is a considerable loss of fat in the feces. Fat content, with a normal diet for adults, is generally 15–20% of the dry weight of feces (ref. 47, p. 349). Measured values for the fat content are 0.57–1.21 g/day with a mean of 0.97 g/day (refs. 47, p. 349; 448, p. 108) or 17.5% of the dry weight or 1.8–6.7 g/day with a mean of 4.1 g/day $\pm$ 0.5 g when the diet contains a moderate amount or about 100 g of fat (ref. 47, p. 349; 608, p. 277). With more fat in the diet, approximately the same proportion is lost in the feces (refs. 9, p. 190; 47, pp. 349–50; 140, p. 524). The fat content of feces for children 10 years old has been reported as 3.7 g/day, and for children 5–12 years old, the range of means was 2.1–3.8 g/day (refs. 47, p. 350; 518, p. 349; 583, p. 1086). In infants (n = 7), fat in feces was reported as 3 g/day with a range of 0.9–7 g/day (refs. 47, p. 354; 258, p. 219, table 3).

The amount of nitrogen in feces may change with the level of nitrogen in the diet, but even when fasting, adults may lose about 0.25 g/day (ref. 47, p. 348). The daily loss for adults on a normal diet is about 1–1.5 g N (ref. 47, p. 348), or 0.8–2.5 g N with a mean of 1.7 $\pm$ 0.1 g (ref. 608, p. 277, table 5 and p. 281), or about 4% of the dry weight (refs. 9, p. 190; 98; 140, p. 524; 529, p. 260). In children, nitrogen loss in wet feces is about 1 g/day (ref. 583, p. 1086). In infants the nitrogen loss in wet feces is about 0.3 g/day with a range of 0.2–0.5 g/day (ref. 258, p. 219, table 3).

Principal components of feces for reference man

	Adult man	Adult woman	Child (10 y)	Infant (1 y)
Weight (g/day)	135	110	85	24
Water (g/day)	105	90	70	19
Solids (g/day)	30	20	19	5
Ash (g/day)	17	15	6	1
Fats (g/day)	5	4.5	4	3
Nitrogen (g/day)	1.5	1.3	1	0.3
Other substances (g/day)	6.5	5	8	0.7

Major elements in feces† for reference man

	Adult man	Adult woman	Child (10 y)	Infant (1 y)
Carbon (g/day)	7	6	4.2	1.2
Hydrogen (g/day)	13	11	8.6	2.5
Nitrogen (g/day)	1.5	1.3	1.0	0.3
Oxygen (g/day)	100	90	62	17

† Fats calculated as $(C_{15}H_{31}COO)_3C_3H_5$; "other substances" calculated as $(C_6H_{10}O_5)_x$.

G. URINE

Within an age group, the daily volume of urine probably increases with body size. The volume is influenced by factors such as water intake, salt intake, high-protein intake, ambient temperature, excessive exercise, and sweating. Circadian changes occur within any 24-h period, with the greatest rate of flow between 3:00 and 6:00 p.m. and the smallest rate between 3:00 and 6:00 a.m. (ref. 140, p. 527). The daily volume of urine for the adult ranges from 500 to 2900 ml, for the child (about 10 years) from 800 to 1400 ml, and for the infant, from 100 to 500 ml (refs. 9, p. 186; 140, p. 527; 327, p. 918). The data in refs. 9 (p. 186), 79 (p. 585), 140 (p. 527), 169, 215, 216, 327 (p. 918), and 503 were used to construct the curves in Fig. 71 showing the relation of urinary volume and age.

Urine consists of 90–98% water (ref. 9, p. 186). The weight of total solids in urine ranges from 26 to 70 g/day for adults (refs. 9, p. 186; 399, p. 1208). In the adult the amount of urea ranges from 14–35 g/day (refs. 9, p. 187; 140, p. 531; 399, p. 1208); "sugars" (based on the reducing properties of certain carbohydrates) range from 0.5 to 1.5 g/day (ref. 140, p. 532); and bicarbonate range from 35 to 840 mg/day (ref. 8, p. 363, using W = 70 kg) with a mean of 140 mg/day. The list of organic constituents in urine may be found in refs. 9 (pp. 186–9), 140 (pp. 527–35), and 327 (pp. 918–36).

For the adult the specific gravity of urine ranges from 1.001 to 1.030 (refs. 140, p. 527; 327, p. 918); for the infant, from 1.002 to 1.019 (refs. 140, p. 527; 327, p. 918); and for the newborn, from 1.004 to 1.019 (ref. 327, p. 918). The pH of urine ranges from 4.6 to 8.0, with an average of 6.2 (refs. 140, p. 527; 327, p. 918; 399, p. 1207).

Urine values for reference man

	Adult man	Adult woman	Child (10 y)	Infant (1 y)
Volume (ml/day)	1400	1000	1000	450
Specific gravity	1.02			1.01
pH	6.2			
Solids (g/day)	60	50	47	19
Urea (g/day)	22			
"Sugars" (g/day)	1			
Bicarbonates (g/day)	0.14	0.12		

Loss of carbon, hydrogen, and oxygen can be calculated from the water, solids, urea, "sugars," and bicarbonates. Nitrogen excretion in adults is 10–20 g/day (refs. 140, p. 528; 399, p. 1207) and in children, 7.5–12 g/day (refs. 285, p. 1009; 340, p. 118; 341, p. 1580).

Urinary loss of major elements for reference man

	Adult man	Adult woman	Child (10 y)	Infant (1 y)
Nitrogen (g/day)	15	13	11	5
Hydrogen (g/day)	160	130	110	50
Oxygen (g/day)	1300	1100	970	420
Carbon (g/day)	5	4	3	0.5

1. Creatinine excretion

Skeletal muscle tissue (and possibly muscle of heart and gut) metabolizes xanthine as a part of its normal metabolism and as a byproduct produces creatinine which is excreted unchanged by the kidney. Creatinine in the diet is also excreted unchanged, but in the normal diet it is present only in trace quantities, if at all. Thus, the quantity of creatinine excreted each day is an index of body muscle mass (refs. 376; 394) and increases during growth (refs. 282; 339; 376; 393; 394; 535). Because a 24-h collection is seldom practi-

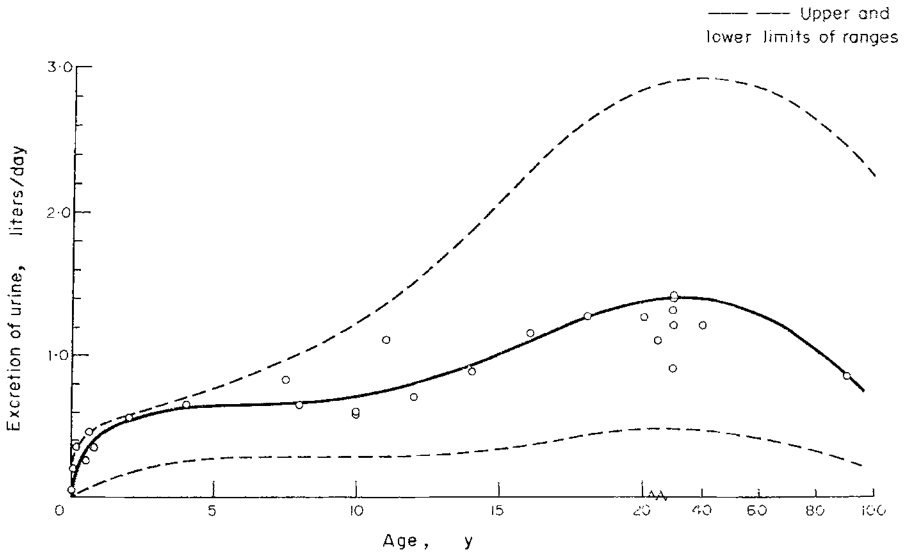

FIG. 71. Daily excretion of urine as a function of age (males only).

cable in industrial situations, a urine sample collected during work time (8 h) can be used to represent a fraction of the daily excretion if an internal standard referred to the creatinine content is used. Standard values of creatinine excretion have been recommended: 1.7 g/day for men and 1.0 g/day for women. Application of these values will give the urine sampling time correctly within a factor of 0.5–1.5 in 95% of the cases (ref. 282, p. 849).

Creatinine excreted will reflect W, or more correctly lean body mass (LBM) (see p. 109), or body cell mass (BCM). Daily excretion of creatinine has been related to BCM: creatinine = 60–80 mg/kg BCM per day (ref. 376, p. 26). It is also related to exchangeable potassium (itself an index of BCM) on the basis of 2.2 meq. K_{ex} = 1 mg creatinine each day for a 70-kg man (ref. 376, p. 27).

The greater proportion of LBM to W of athletes is reflected in a greater creatinine excretion, but there is no increase with muscular activity (ref. 282, p. 847, table 2). Diurnal variation in creatinine is scarcely perceptible (ref. 282, p. 844).

The relation of daily creatinine excretion with age and sex is illustrated in Fig. 72 and based on data derived from refs. 140, 282, 339, 376, 393, 394, and 535.

H. MILK CONSUMPTION

Data from North American, Western European, and Australian surveys and studies are plotted in Fig. 73, and calculated representative intakes for males and females in relation to age are given in Table 125 (refs. 57; 126; 150; 365; 377; 570; 594). In Fig. 73 mean values for milk intake from the referenced literature are plotted for ages > 1 year. The curves drawn in the figure are of the representative calculated values in Table 125. Milk consumption by adults may vary widely according to personal preference. In children and infants, milk usually represents an important fraction of the total diet and of daily fluid intake, and the range of values reported for individual consumption tends to be less for infants and children than that of adults.

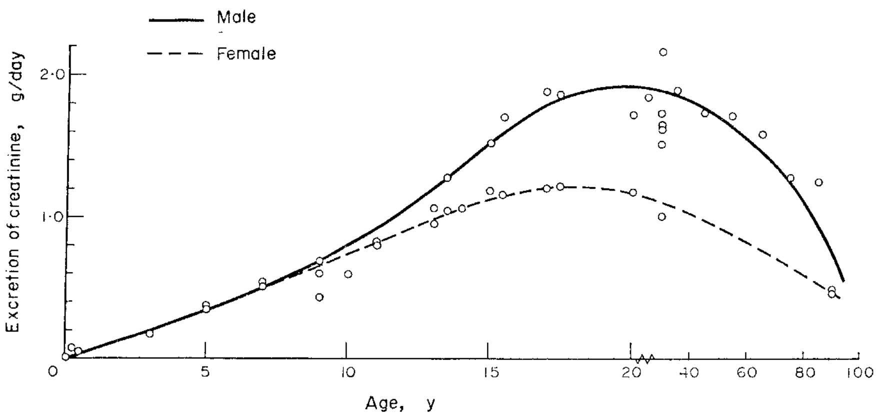

FIG. 72. Daily excretion of creatinine as a function of age and sex.

TABLE 125. MODEL MILK CONSUMPTION (ml/d)

Age (y)	Male	Female
0.25	750	600
0.50	1000	800
0.75	850	650
1	580	500
2	500	440
3	490	440
4	490	430
5	490	430
6	490	440
8	490	440
10	480	420
12	470	390
15	440	330
17	410	280
20	330	200
40	270	140
60 and > 60	250	130

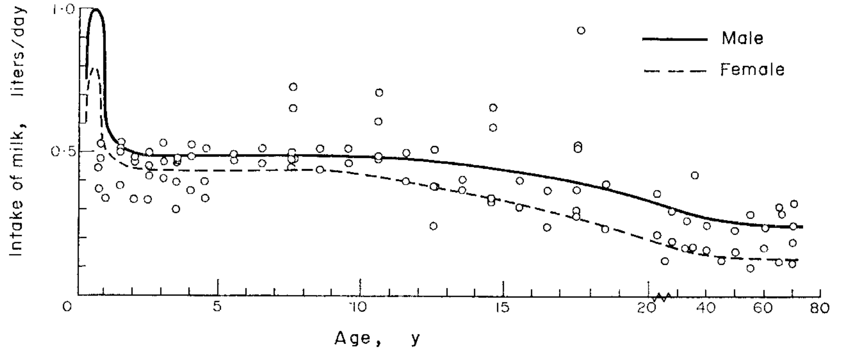

FIG. 73. Daily intake of milk as a function of age and sex.

The pattern of consumption by infants, as shown in the curve of Fig. 73 and in Table 125, is relatively well established. Milk consumption is maximal at 5–6 months (ref. 178) and then declines with the introduction of solid foods in the infant's diet (refs. 29; 124, 175; 178; 388; 424). The curves drawn are representative of the data quoted in the listed references.

The proportion of total milk consumed as dried or canned milk was about 6% in 1964 in the United Kingdom (see p. 349) and about 5% in 1959/63 in the United States (ref. 558) (based on household consumption estimates).

National values of *per caput* milk consumption (Table 126) are derived from family purchase or consumption studies. They give some indication how the model values of Table 125, derived for Western European or North American populations, might be adjusted for other communities.

TABLE 126. DAILY MILK CONSUMPTION IN DIFFERENT COUNTRIES
(refs. 124; 254, p. 77, table 4.7)

Country	Date of survey	g/caput (approx.)
Europe		
CEE	1963–5	290
United Kingdom	1957/8–1959/60	590
Western Germany	1957/8–1959/60	620
Finland	1957/8–1959/60	980
Portugal	1957–9	98
North America		
Canada	1957/8–1959/60	760
USA	1957–9	750
Latin America[a]	1957–9	280
Far East		
China (Taiwan)	1957–9	17
India and Pakistan	1957/8–1959/60	130
Japan	1957–9	50
Africa and Near East		
Israel	1957/8–1959/60	520
South Africa	1957–9	240
UAR	1957/8–1959/60	120
Oceania		
Australia	1957/8–1959/60	560

[a] Mean of values for Argentina, Brazil, Mexico, and Venezuela.

For the intake of milk for children at different ages, Table 125 and Fig. 73 may be used.

Intake of milk for reference man

Adult man	Adult woman	Child (10 y)
300 ml/day	**200 ml/day**	**450 ml/day**

I. TOTAL FLUID CONSUMPTION

Surveys of total fluid consumption by adults or children in the normal range of environmental conditions are very rare. Family or household purchase or consumption surveys are seldom adequate for estimation of fluid intake; sometimes drinks (other than milk) are not recorded, and also since many drinks are taken casually outside of normal meal-times or outside the household, they are seldom recorded. The available data, together with some for other conditions of exercise and environmental temperature, are summarized in Table 127. If a study of the total fluid consumption of a limited

TABLE 127. MEASURED FLUID INTAKES (ML/DAY)

<table>
<tr><th>Subject</th><th>Total fluids</th><th>Milk</th><th>Tap water</th><th>Water-based drinks[a]</th></tr>
<tr><td>Adults ("normal" conditions) (refs. 7; 14; 56; 58; 126; 216; 257; 357; 453; 549)</td><td>1000–2400</td><td>120–450</td><td>45–730</td><td>320–1450</td></tr>
<tr><td>Adults (high environmental temperature to 32°C) (refs. 215, p. 94; 319)</td><td>2840–3410
3256 ±
SD = 900</td><td></td><td></td><td></td></tr>
<tr><td>Adults (moderately active) (ref. 216)</td><td>3700</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Children (5–14 y) (refs. 49; 56; 126; 192; 340, p. 114; 388; 499; 582)</td><td>1000–1200</td><td>330–500</td><td>ca. 200</td><td>ca. 380</td></tr>
<tr><td>1310–1670</td><td>540–650</td><td colspan="2">540–790</td></tr>
</table>

[a] Includes tea, coffee, "soft drinks," beer, cider, wine, etc.

population is made, as, for example, that of Bransby and Fothergill (ref. 56) of 270 persons in a London suburb, differences of intake from the national average may be noted. These authors reported about 1950 ml/day as a total fluid intake for a man; but within the group studied, 230 ml/day of beer or cider was reported, which was less than the national *per caput* consumption of beer in the United Kingdom for 1963 (ref. 58). It may be noted that the reference value (p. 360) for total fluid intake of adults lies above most published values of daily fluid intake. This has been done on the basis of theoretical considerations of total water balance and on the physiological premise that 1 ml of water (including that in food and obtained by the body's metabolic oxidation of food) is required for each kilocalorie of energy expended.

J. MODEL FOR WATER BALANCE

A model for water balance is difficult to derive except on quite theoretical grounds because of the scarcity of adequate data for normal temperate conditions of environment or activity (p. 358). More information is available about extreme conditions (refs. 3; 314; 317; 389; 495). In addition, considerable variation is found among individuals or within the same individual on successive occasions; only a part of this variation can be attributed to changes in environment and to differences in age, sex, body weight, or surface area. Over long periods, homeostasis of body fluids and tissues will ensure that water gains exactly balance water losses, and this can be observed in long-term studies where weight change (i.e., tissue weight change) is avoided. However, many short-term studies do not demonstrate precise balance; dehydration and "hyperhydration" to the extent of 2–5% of total body weight can be tolerated without functional disturbance (ref. 317, p. 565). Studies of water balance should be considered within such degrees of tolerance.

1. WATER INTAKE

Total fluid intakes from experimental studies have been summarized in Section I (see p. 358). For the adult Reference Man, the daily consumption of fluids is about 1900 ml (see p. 358), but actual values may range from 1000 to 2400 ml/day at moderate temperatures. An attempt has been made to allocate this total to the principal component of fluid intake. Estimates for milk and tap water intakes are relatively well documented, but values for other water-based fluids are likely to be underestimated (see p. 358). Milk constitutes about 12% of total adult fluid intake, tap water perhaps less than 10%. For children, total intakes are closely related to body size and age, but the contribution from different components is variable. Commonly milk is 40% of the total fluid intake (in the UK the USA, and Australia) and tap water is about 12%.

Environmental temperature and body activity influence fluid requirements. At low temperatures (Fig. 74) fluid intake and water losses are scarcely affected by ambient temperature or activity; but at temperatures greater than 25°C, there is a sharp rise in water intake, largely to meet the demands of an increased sweat rate (ref. 215). There is some decline in urine flow at high temperatures (ref. 591, p. 145). Insensible water loss is relatively constant in variable conditions.

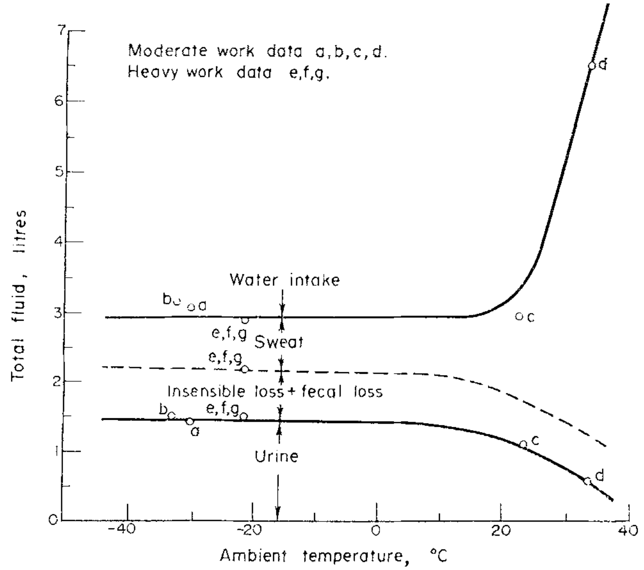

FIG. 74. Relation of mean daily total water intake and urine output in litres per man to mean daily outdoor ambient temperature. (By permission of Welch *et al.*, ref. 591, p. 145.)

2. WATER LOSSES

Water is lost from the body by a number of routes—in urine, in feces, and through the skin as sweat or by diffusion and transpiration. Losses via urine and feces have been discussed (see pp. 354–355 and pp. 352–353).

Insensible water loss is related to body surface area, body weight, body temperature, and metabolic rate. The total daily loss through the skin is estimated to be 75–300 ml for infants (2–10 kg W), 300–600 ml for children (10–40 kg W), 600–1000 ml for adolescents and adults (60 kg W) (observed range 350–1900 ml) (refs. 79, p. 585; 216, p. 318; 477, p. 344). (See also refs. 34; 36; 67; 68; 529, pp. 172–176). Of this total, about one-quarter to one-third is lost via the lungs in expiration and two-thirds to three-quarters through the skin (ref. 313, p. 28). Skin loss has been divided into transepidermal (diffusion) loss and insensible sweat loss (ref. 44, p. 627).

Sweat loss is exceedingly variable, depending on SA, W, environmental temperature, activity and wind speed. For a reference man (70 kg) engaged in light, indoor activities for 8 h a day, in a temperate environment, the sweat loss is estimated at 650 ml/day. For specific estimates in other conditions of environmental temperature and activity, nomograms should be used (refs. 389, pp. 278–9; 495).

Water balance for reference man

	Adult man		Adult woman		Child (10 y)	
	Gains (ml/day)	Losses (ml/day)	Gains (ml/day)	Losses (ml/day)	Gains (ml/day)	Losses (ml/day)
Milk	300	1400 in urine	200	1000 in urine	450	1000 in urine
Tap water	150	100 in feces	100	90 in feces	200	70 in feces
Other	1500	850 insensible loss	1100	600 insensible loss	750	580 insensible loss
Total fluid intake	1950		1400		1400	
In food	700	650 in sweat	450	420 in sweat	400	350 in sweat
By oxidation of food	350		250		200	
Totals	3000	3000	2100	2100	2000	2000

Other secreted fluids (mucus, semen, tears, saliva, etc.) will not affect significantly the water balance model. Secretion of milk by nursing mothers presents a special case, and a daily volume of 850 ml is suggested as a reference value (see section K below).

K. LACTATION

The reported range of volumes for milk secreted is 500–1000 ml/day (ref. 623, p. 330), although maximal values up to 3 l/day have been recorded (ref. 477, p. 340). A reasonable maintained average is 850 ml/day (ref. 623, p. 330), and this has been selected as a reference value.

Human milk is rich in nutrients, and its secretion represents a considerable depletion of maternal stores, especially of sodium, potassium, calcium, iron, iodine, and chlorine. While an augmented intake of food and water will normally counterbalance the increased loss of fluid and bulk components, in a diet already deficient in minor elements, the augmented intake does not compensate the loss. The composition of mature human milk is listed in Table 128.

Daily calorie requirement of the Reference Woman is 2100 kcal; the additional requirement for lactation is estimated to be 180,000 per 6 months (section B, p. 343). Thus, the daily calorie requirement of the lactating woman would be 3100 kcal, or an increase of 43.5%. Hence about 40% of the daily intake of iodine and zinc; about 30% of the daily intake of calcium; 15–20% of copper, selenium, and sulfur; and 10–14% of iron, manganese and potassium are secreted in 850 ml of milk.

TABLE 128. COMPOSITION OF HUMAN MILK[a]
(concentrations expressed as mg/100 ml milk unless stated otherwise)

Constituent	Range	Mean	Refs.
Water (ml/l)	830–900	870	6, p. 111; 343, p. 594; 503, p. 50
Specific gravity	1.026–1.037	1.031	10, p. 5; 140, p. 514; 343, p. 594
Total solids (g/100 ml)	10.3–17.5	12.9	6, p. 111; 140, p. 514; 343, p. 594; 503, p. 50
Fats	1300–8300	4500	140, p. 514, 343, p. 594
Protein	1200–2700		306, vol. 2
Carbohydrates (lactose)	4900–9500	7100	140, p. 514; 343, p. 594
Aluminium		0.033	10, p. 5
Calcium	17–61	34	6, p. 111; 140, p. 514; 343, p. 594; 410, pp. 606, 610; 481, p. 396
Carbon		6.1[b]	
Chlorine	8.8–73	37	343, p. 594
Cobalt		0.1×10^{-3}	10, p. 5
Copper	0.02–0.10	0.045	6, p. 111; 10, p. 5; 247, p. 727; 503, p. 50; 623, p. 337
Fluorine	<0.1–0.2 ppm		610, p. 276
Hydrogen		11[b]	
Iodine	2×10^{-3}–15×10^{-3}	7×10^{-3}	6, p. 111; 10, p. 5; 503, p. 50; 514, p. 434
Iron	0.02–0.45	0.15	10, p. 5; 503, p. 50; 514, p. 431
Magnesium	1.8–5.7	3.5	6, p. 111; 140, p. 514; 343, p. 594; 411, p. 645
Manganese	0.7×10^{-3}–10^{-3}	0.7×10^{-3}	6, p. 111; 10, p. 6; 140, p. 514; 503, p. 50
Nitrogen		515	10, p. 4; 306, vol. 2
Oxygen		82[b]	
Phosphorus	6.8–27	14	6, p. 111; 140, p. 514; 343, p. 594; 503, p. 50
Potassium	37–63	51	6, p. 111; 140, p. 514; 343, p. 594; 503, p. 50
Selenium	1.3×10^{-3}–6.2×10^{-3}	2.1×10^{-3}	220, p. 274
Silicon		0.034	10, p. 6
Sodium	6.4–44	17	140, p. 514; 343, p. 594
Sulfur	5–30	14	6, p. 111; 140, p. 514; 343, p. 594; 503, p. 50
Zinc	0.02–1.4	0.53	6, p. 111; 10, p. 6; 503, p. 50

[a] Only mature milk, 2 weeks after the onset of lactation, is considered here.
[b] Calculated values derived from water, fat, and lactose in milk.

L. COMPOSITION OF SWEAT

Reference values for elements in sweat cannot be set without reference to the rate of flow and method and site of collection. Sweat collected by practicable methods for analysis represents the combined output of a great many glands. The density on the skin surface and secretory capacity of the glands vary between different regions of the skin in the same individual and between identical regions of the skin in different people. The rate of secretion of sweat greatly affects its composition. At low rates of secretion, the concentration of sodium and chlorine is greater in sweat than in blood; but at high rates (when resorptive mechanisms cannot act quickly enough, or are of limited capacity), the concentrations in sweat approach those in blood. Thus, the concentration of sodium can vary from 12 mg per 100 ml at high rates of secretion to values as high as 890 mg per 100 ml at low rates. Higher values are probably due to methodological factors or physiological variables other than secretory rate (ref. 311, p. 440). Chloride follows the same general trend as sodium. A number of investigators have confirmed that the median sodium-chloride ratio is 1.11 with a range of 0.97 to 1.43 (refs. 311, p. 440; 436, p. 205), or Na = (1.12 × Cl) + 3 meq./l (refs. 311, p. 440; 436, p. 205); but ratios from 0.7 to 2.0 also have been reported (ref. 477, p. 354). Sweat losses significantly affect the metabolic balance of sodium, chloride, potassium, and iron as well as of nitrogen with diets low in protein. Sweat composition in the particular circumstances of an experiment or test is discussed in many review articles (refs. 311; 313; 436; 477).

Sweat production per square meter SA in men is greater than in women, but the difference is insignificant; in children, production per square meter SA is about half that of an adult population (ref. 143, p. 28). Sweat volumes can vary over a very wide range; a 65-kg man engaged in light indoor activity at 29°C will produce 2–3 l/day; and if temperature or activity is increased, rates as high as 15 l/day are observed (ref. 477, p. 349). Data for the elemental composition of sweat and elemental loss through sweat are presented in Table 129. For computation of model values, a daily sweat volume of 650 ml is used for Reference Man (see p. 360) with appropriate levels of concentration where data are available.

TABLE 129. OBSERVED SWEAT COMPOSITION

Element	Concentration range (mg per 100 ml)	Refs.	Loss (mg/d)	Refs.
Aluminium			6.1[a]	112, p. 9
Bromine	0.018–0.05	477, p. 361		
Calcium	0.3–12	ref. 6, p. 214; 8, p. 467; 19; 313, p. 224; 367, p. 349; 436, p. 210; 477, p. 357	150–160 15–30	110, p. 444; 199, p. 42; 367, p. 358
Chlorine	36–1000	8, p. 467; 140, p. 543; 313, p. 224	31 (3-mo infant) 28 (6-mo infant)	531, p. 1038
Chromium			0.059[a]	112, p. 9
Cobalt			0.017[a]	112, p. 9
Copper	$(4.4–8) \times 10^{-3}$	6, p. 214; 367, p. 349; 436, p. 210; 477, p. 360	1.6[a]	112, p. 9
Fluorine	$(7–180) \times 10^{-3}$	391, p. 428		
Hydrogen			$0–1.7 \times 10^{6}$	

Continued

TABLE 129. OBSERVED SWEAT COMPOSITION (*continued*)

Element	Concentration range (mg per 100 ml)	Refs.	Loss (mg/day)	Refs.
Iodine	$(0.5–1.2) \times 10^{-3}$	6, p. 214; 8, p. 467; 112, p. 9; 313, p. 224; 477, p. 361	0.024[a] 0.15[a]	112, p. 9 110, p. 446, table VII
Iron	0.02–2	6, p. 214; 8, p. 467; 313, p. 224; 367, p. 354; 422, p. 87; 436, p. 211; 477, p. 358	0.3–6.5	109,[b] p. 409; 145, pp. 608–10; 241, p. 330; 367, pp. 354, 360
Lead			0.26[a]	477, p. 360
Magnesium	0.004–4.5	6, p. 214; 8, p. 467; 19; 313, p. 224; 367, p. 349; 436, p. 210; 477, p. 358	1.5; SD $\pm$ 0.3	199, p. 42
Manganese	$(3.2–7.4) \times 10^{-3}$	6, p. 214; 8, p. 467; 367, p. 349; 477, p. 360	0.097[a]	112, p. 9
Mercury	Present	477, p. 360		
Molybdenum			0.061[a]	112, p. 9
Nickel			0.083[a]	112, p. 9
Nitrogen	12–200	8, p. 467; 313, p. 236; 367, p. 350; 436, pp. 213–15; 477, p. 362	300–380[a] 53–170 (7–16-mo infants)	110, p. 445; 176, p. 495; 367, p. 350; 477, p. 362 176, p. 496
Oxygen			$0–13 \times 10^6$	
Phosphorus	0.003–4.8	6, p. 214; 8, p. 467; 367, p. 349; 436, p. 210; 477, p. 361	0.3; SD $\pm$ 0.11	199, p. 42
Potassium	3.9–150	6, p. 214; 8, p. 467; 140, p. 543; 313, p. 224; 436, pp. 209–10; 477, p. 361	68 (3-mo infant) 60 (6-mo infant) 33; SD $\pm$ 17 590–1800[a]	531, p. 1038, table 3 199, p. 42 109, p. 410, table 5
Selenium			0.34[a]	112, p. 9
Silver	present	477, p. 360		
Sodium	11–890	6, p. 214; 8, p. 467; 140, p. 543; 313, p. 224; 436, pp. 204–9; 477, p. 352; 498, p. 604	15 (3-mo infant) 11 (6-mo infant) 71; SD $\pm$ 25	531, p. 1038, table 3 199, p. 42

Continued

TABLE 129. OBSERVED SWEAT COMPOSITION (*continued*)

Element	Concentration range (mg per 100 ml)	Refs.	Loss (mg/day)	Refs.
Strontium			0.02	144, p. 200
Sulfur	0.7–7.4	6, p. 214; 8, p. 467; 313, p. 224; 436, p. 210; 477, p. 361		
Tin			2.2[a]	112, p. 9
Zinc	0.085–0.15	422, p. 84	2.3[a]	112, p. 9

[a] Value obtained during "copious sweating," i.e., subject engaged in light sedentary activity at 100°F = 38°C for 7.5 h. Loss during remainder of 24 h assumed to be negligible.
[b] Mitchell *et al.* (ref. 367) give 6.5 mg/d for men, 0.4 mg/d for women. Consolazio *et al.* (ref. 109, p. 409, table 2) found only 1 mg Fe/day for men exposed to 100°F = 38°C for 7.5 h.

M. COMPOSITION OF SALIVA

Although up to 2 l of saliva may be secreted daily, there usually is little loss, as the bulk is swallowed and reabsorbed in the GI tract. In young babies who lack an efficient swallowing reflex, the sodium balance might be affected in critical situations.

The composition of saliva is presented in Table 130.

TABLE 130. COMPOSITION OF SALIVA (mg per 100 ml, unless specified otherwise)

Component	Mean	Range	Ref.
Volume		1–2 l/day	140, pp. 517–19
Specific gravity		1.002–1.008	140, pp. 517–19
Water	99.5 g per 100 ml		140, pp. 517–19
Bromine		0.02–0.71	140, pp. 517–19
Calcium		4.5–10	140, pp. 517–19
Chloride[a]	100	40–165	140, pp. 517–19
Cobalt	7.0 μg per 100 ml		140, pp. 517–19
Copper	26 μg per 100 ml		140, pp. 517–19
Fluorine		10–20 μg per 100 ml	140, pp. 517–19
Iodine	10 μg per 100 ml	3.5–24 μg per 100 ml	140, pp. 517–19
Magnesium	0.7	0.19–1.3	5, p. 64; 140, pp. 517–19
Nitrogen[b]	90	36–125	503, p. 60
Phosphorus	20	12–29	140, pp. 517–19
Potassium[a]	77	46–108	140, pp. 517–19
Sodium[a]	400	200–550	503, p. 60
Sulfur	7.6		140, pp. 517–19

[a] Sodium and chloride in saliva vary with rate of flow according to the relation mg Na per 100 ml = 18.19 minute vol. (ml) + 19.04, because they are resorbed from the primary secretion by a system of limited capacity. Concentration of potassium is relatively unaffected by secretory rate.
[b] Production of saliva stimulated by chewing paraffin.

N. COMPOSITION AND FLOW OF NASAL SECRETION

The concentration of inorganic ions in nasal secretion is inversely related to the daily volume. Data on the elemental composition of nasal secretion is presented in Table 131. Flow ranges from 500 to 1000 ml/day (ref. 423, p. 322). The bulk of the secretion will find its way to the GI tract.

TABLE 131. SOME MAJOR ELEMENTS IN NASAL SECRETION (ref. 354)

Water	95–97 g per 100 ml
Calcium	11 mg per 100 ml
Chlorine	495 mg per 100 ml
Potassium	69 mg per 100 ml
Sodium	295 mg per 100 ml

O. SUMMARY OF MODEL VALUES FOR DAILY BALANCE OF ELEMENTS IN REFERENCE MAN

Page ref.	Element	Intake		Losses			Units
		Food and Fluids	Airborne	Urine	Feces	Others	
367	Aluminium	45	0.10	0.10	43	1 sweat 0.0006 hair	mg
368	Antimony	~50	0.05	~40	~9	1 hair	μg
369	Arsenic	1.0	0.0014	0.05	0.8	0.5×10^{-3} hair and nails 0.15 other losses	mg
370	Barium	0.75	$0.09–26 \times 10^{-3}$	0.05	0.69	0.01 sweat 0.075 hair	mg
371	Beryllium	12	<0.01	1.0	10	1 other losses	μg
371	Bismuth	20	<0.01	1.6	18	Not known	μg
372	Boron	1.3		1.0	0.27	<0.001 hair	mg
372	Bromine	7.5		7.0	0.07	0.19 sweat 0.01 other fluids 0.002 hair	mg
373	Cadmium	150	<1	100	50		μg
374	Calcium	1.1		0.18	0.74	0.032–0.15 sweat Trace other fluids and hair	g
377	Carbon	300		5.0	7.0	270 exhaled 18 other losses	g
378	Cesium	10	0.025	9.0	<1.0	Sweat	μg
378	Chlorine	5.2		4.4	0.05	0.78 sweat 0.05 other fluids	g
380	Chromium	150	0.1	70	80	1 sweat 0.6 hair Trace other fluids	μg
381	Cobalt	300	<0.1	200	90	4.0 sweat 2.4 hair Trace other fluids	μg
382	Copper	3.5	0.02	0.05	3.4	0.040–0.40 sweat 0.003 hair and nails 0.020 menstrual loss Trace other fluids	mg
383	Fluorine	1.8		1.0	0.15	0.65 sweat Trace other fluids	mg

Continued