Dietary Prescription of Water, Sodium, Potassium, Calcium and Phosphorus for Infants and Children

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PHYSICIANS prescribing diets for children must recognize the two distinctive functions of foodstuffs.[1] The first is to supply those substances that sustain the structural machinery of the body. The second is to furnish energy for this machinery. The specific units of the mobile and the stationary chemical structure cannot be provided by substituting large amounts of other substances. When used for energy foodstuffs are widely interchangeable.

The danger in considering specific nutrients is that by so doing we may displace our emphasis which must always be upon foods with their unknown as well as known contributions. Our patients will not benefit from our knowledge of nutrition except as we talk to them in terms of household measures of common foodstuffs. Specific prescriptions must be used as to the types and amounts of food and not vague statements about eating "a well balanced diet".[2]

The advantage of considering specific nutrients is that by so doing we see more clearly the interrelationships of foods and the need for a variety of natural foods. We are also more aware of the areas where additional research is required. Such considerations point out how unsound and inadequate it is to resort to multiple concentrates of "known" nutrients in attempting to provide good nutrition.

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Some of the indispensable structural elements are stored in fair quantity against intervals of deprivation, whereas no appreciable stores exist for others, such as water, sodium and potassium. For each of these intake must continuously balance outgo. The physician, to provide their intake without causing insufficiency or excess, needs to consider their outgo and the range over which outgo may wander in health.

WATER

The prescription of water intake for healthy children presents no problem once the child can express his thirst in a meaningful way so that he is given water or can get it for himself whenever he is thirsty. Prior to reaching this stage of development, the water intake must be prescribed. To do this requires an understanding of water expenditure in health.[3]

The insensible losses of water from the lungs and skin amount to 42 ml of water per 100 cal metabolized, which, *for the infant*, is conveniently approximately equivalent to the same figure per kilogram of body weight. The water required for urine formation is proportional to the load of substances, chiefly urea and electrolytes to be excreted by the kidneys, and is inversely proportional to the concentration of the urine.[4] Table I illustrates the effect of the type of diet and the concentration of the urine on the range of urine volumes. Water lost in the stools is negligible and that required for growth (about 70 ml per 100 g gained) is also of minor importance in calculating daily water expenditure. Although sweat is generally considered an abnormal loss, there is evidence that infants, children and

TABLE I

Urine Volumes Required by Different Diets
(Urine Volumes in ml/kg/day)

Type of diet	Approx. renal osmolar load mosm/kg	Concentration of urine: Dilute	Iso-tonic	Maxi-mally concen-trated
Low-protein low-mineral (human milk)	14	190	45	12
Average (diluted cow's milk with added carbo-hydrate)	21	250	67	17
High protein high mineral	45	560	145	40

adults in comfortable environmental temperatures usually produce about 10 g of perspiration per 100 cal metabolized.[3] Therefore, for the healthy infant, water intake and the water of oxidation (about 12 ml per kg) together should furnish each day around 50 ml per kg of body weight for insensible losses plus slight sweating, 70 ml per kg for urine formation for the artificially fed infant (45 ml for breast fed) and an additional 25 to 50 ml per kg as a margin of safety, especially against increased perspiring. An appreciation of these physiologic principles allows the physician to anticipate the effects of prescribing more dilute or concentrated feeding mixtures or those high in protein or electrolytes. Thus the use of more dilute cow's milk mixtures for the first week of life is advocated because they impose a lighter renal load at a time when renal concentrating power is low. Similarly, the rationale of the "routine" use of cow's milk mixtures having 20 per oz (670 cal/lit for young infants can be appreciated, since the water requirement will automatically be met if the caloric intake is adequate. For the older infant, liquids in addition to his milk may be furnished to maintain his water intake at a proper level.

SODIUM AND POTASSIUM

In health, the amounts of sodium and potassium in the body are regulated primarily by the dietary intake and the renal output of these ions. They are almost completely absorbed from the gastrointestinal tract, and amounts absorbed in excess of the body's needs for growth are promptly excreted in the urine. The allowances for sodium and potassium, like other structural chemical units, are best viewed in terms of minimal requirements and the maximal amounts that can be physiologically tolerated. The minimal amounts of these two minerals depend largely on the quantities needed for growth, for the usual sweating, and on their conservation by the kidneys.

The requirements for growth are difficult to estimate. The "precise misinformation"[1] of balance studies has confused this subject. Extrapolation of the "retentions for growth," especially those for infants fed cow's milk compared with those fed human milk, could only lead to widely varying composition of the body fluids. Yet whole body analyses and isotope dilution studies indicate a quite constant composition of this portion of the body (except for its fat content). The composition of bone may be less constant, and the content of calcium and phosphorus in bones may vary with intake. The best estimates for growth in young infants are, for each kilogram of body weight gained, around 76 meq of sodium, 58 meq of chloride and 46 meq of potassium,[5] although these values may be 5 to 10 per cent too high judging from the isotope dilution studies.

Under comfortable environmental conditions a small amount of perspiration is formed. Recent data indicate that the losses of sodium and potassium were originally estimated too high and that more realistic figures are of the order of 0.1 to 0.2 meq of sodium and chloride as well as for potassium per 100 cal metabolized during infancy.[6]

The urine, except in the neonatal period, may be rendered nearly free of electrolytes so that minimal urinary losses are approximately 0.2 meq of sodium and chloride and 0.4 meq of potassium per 100 cal metabolized.[3] Stool losses are around 0.2 meq of each of these electrolytes per 100 cal metabolized.

For practical purposes, the lowest usual daily intakes of sodium and potassium for young infants are those supplied by human milk. An infant ingesting 165 ml of human milk per kg of body weight per day ($2^1/_2$ oz/lb) would receive about 1 meq of sodium (23 mg), 2 of potassium (78 mg) and 1.7 of chloride (60 mg) per kg of body weight.[7]

The maximal intakes of sodium and potassium that can be tolerated have not been defined. High intakes of sodium have an adverse effect on potassium balance and vice versa,[8] and high electrolyte intakes demand a large supply of water for urine formation. A practical upper limit of daily sodium and potassium intake in infancy may be taken as the amounts ingested by an infant taking 110 cal per kg of body weight per day of skimmed cow's milk. Under these circumstances the intake of sodium and potassium would be about 8.0 (185 mg) and 11.0 (430 mg) meq/kg/day respectively.

For older children, low-sodium diets containing as little as 2.5 meq (58 mg) of sodium daily have been used.[9] Probably much above 260 meq of sodium (6 g of sodium; 15 g of NaCl) per day are not well tolerated. Data for minimal and maximal daily amounts of potassium for children and adolescents are unknown, but probably are in the range of 40 meq (1.6 g) to 250 meq (10 g) per day (10). Ordinary diets for 12-year-old children provide about 90 meq of potassium daily and additions of 150 meq per day have been used without harmful effects.[9]

Therefore, the conclusion is that suitable amounts of sodium and potassium are provided by simple milk diets in infancy and by all well balanced diets for children. Potassium is not apt to be present in either too small or too large amounts. Sodium in ordinary good diets is generally ample for all conditions, except possibly strenuous exercise by older children is hot humid environments. Added salt is not needed nor helpful in the diets of healthy infants in hot weather. Excessive sodium intake may occasionally occur because too much salt is added to foods during preparation or at the table.

CALCIUM AND PHOSPHORUS

Assessing the needs for calcium and phosphorus is difficult because the large stores provide for long periods of depletion or repletion without leading to recognizable changes in well being, thus making for much speculation as to the significance of the balances which have been obtained under varying conditions of intake, age and states of health. Analyses of the amounts of calcium and phosphorus in bodies at varying ages could provide data to calculate requirements, but the variability of the few analyses available and particularly the suspicion that the subjects were not in good nutritional condition invalidate such calculations.[10] Are we justified in concluding that because increased intakes of calories, protein and calcium produce taller, heavier framed adults, these intakes are better nutritionally; or that such diets used in early life will lessen the incidence of bone disorders in the adults, or alter the extent of cardiovascular degenerative diseases? Henry and Kon[11] found that growing rats given low-calcium diets deposited it more slowly than those on higher intakes, although eventually bone analyses showed similar calcium content for all rats. However, senescent rats accustomed to do with little calcium in the diet remain in calcium equilibrium in circumstances leading to calcium loss in rats used to a higher intake. Thus it appears that the way calcium stores are accumulated may determine the plane of calcium metabolism. Either the slowly acquired stores are more tenaciously held or those rats have developed a more efficient turnover of calcium. If humans could be shown to behave in a similar manner, calcium intakes lower than those generally advocated might be desirable for children.

Phosphorus intake will be ample in diets with adequate amounts of protein and calcium. Hence, this discussion will deal chiefly with calcium, although it is evident from Figure 1 that the status of calcium in the body fluids depends not only on the flow of calcium into and out of the body fluids but also upon the rates of entrance and exist of phosphorus. The phosphorus concentration in the circulating fluids is determined by the rate of absorption from the gastrointestinal tract and the equilibrium with the intracellular and skeletal phosphates as well as alterations in renal excretion.[12] A resume of the factors influencing calcium and phosphorus metabolism is given in Figure 1.[13,14] Thus it is obvious that the requirement of these minerals may vary widely, and that minimal and maximal amounts tolerated in the diet cannot be readily defined under most circumstances. Data on the quantities of *endogenous* calcium excreted in the feces at different ages, as well as on the factors influencing this route of excretion, would help load incurred by cow's milk feedings,[17,18] the low glomerular filtration rate of this period[19,20] and the influence of stress, both in releasing phosphorus from body tissues and in reducing glomerular filtration.[21] Temporary parathyroid hypofunction probably plays a role,[22] although lack of agreement[20,23] as to what objective evidence indicates parathyroid activity leaves its role uncertain. Figure 1 demonstrates that the observed values of serum calcium and phosphorus in neonatal hypocal-

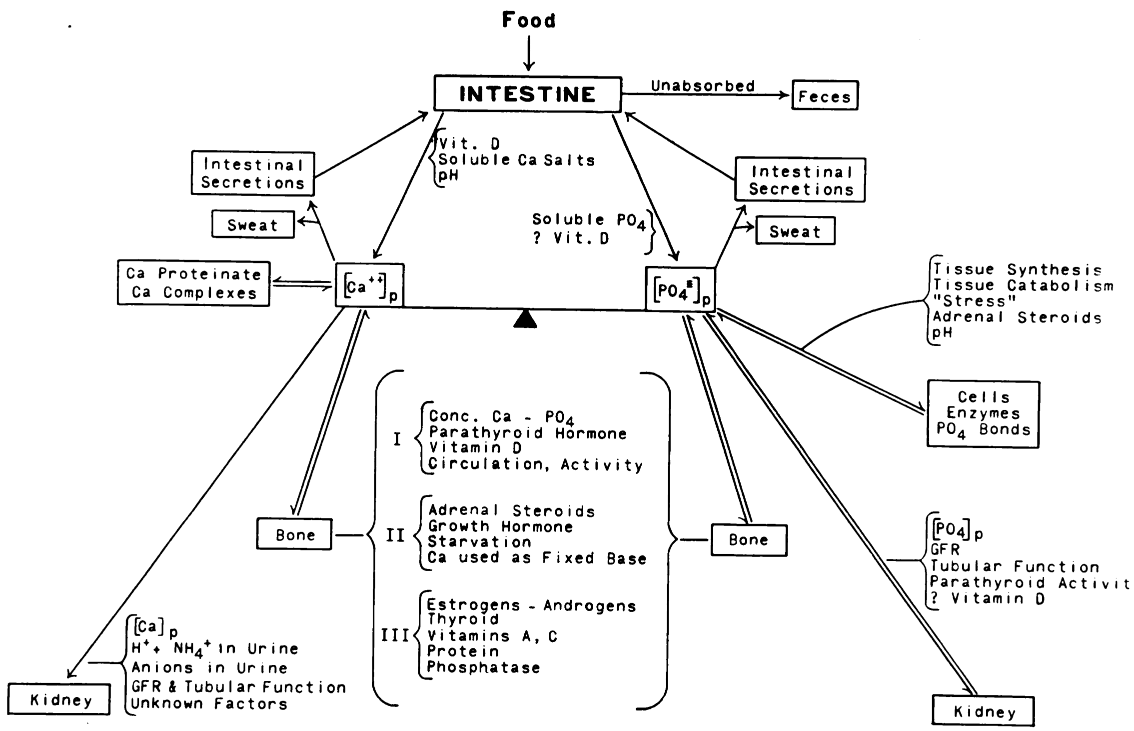

Fig. 1. Factors influencing calcium and phosphorus metabolism[12,13]. Those affecting bone are subdivided: I are those quite well understood, II those about which something is known, and III those dimly discerned.

in defining the utilization of dietary calcium.[15] Perhaps the great variability of the human organism in its disposal of dietary calcium and particularly the marked ability of the body to adapt itself to a wide range of calcium intakes are the major factors leading to our uncertainty as to the requirement of this mineral.[16]

In the neonatal period, hypocalcemia is occasionally noted. An extensive literature attempting to explain the causes for these cases stresses the factors of the high phosphate cemia could be brought about by any or all of these factors, and not necessarily by diet alone.[24]

In artificially fed infants the use of a special modification during the neonatal period is generally prescribed for the reasons discussed under water requirement and in this section, although there is not unanimous agreement as to the need for such mixtures. A commonly employed mixture during the first week of life is: cow's milk 1 part, water 2 parts, added carbohydrate 5 to 10 g per 100 ml, with or without the addition of 0.28 g of calcium gluconate per 100 ml.[17]

Beyond the first week of life, artificially fed infants on cow's milk modifications providing 120 mg of calcium per kg per day are generally believed to have an adequate calcium intake if 400 to 800 units per day of vitamin D are taken. This amount of calcium is furnished by cow's milk modifications in which $^2/_3$ or $^7/_{10}$ of the calories come from cow's milk and the other $^1/_3$ or $^3/_{10}$ of the calories from added carbohydrate. There is evidence that calcium intakes of 50 mg/kg/day with adequate amounts of vitamin D are about the minimal calcium intake for infants fed *cow's* milk mixture.[10]

For healthy, full term infants the relatively small amounts of calcium ingested from human milk, around 40 to 60 mg/kg of body weight per day, seem adequate if about 400 units of vitamin D per day are taken. The absorption of calcium from human milk ranges from 50 to 70 per cent.

From infancy to around 8 years of age the generally accepted daily intake of calcium ranges from 70 mg/kg of body weight for the three-year-old child to 45 mg/kg of body weight for the eight-year-old child. Three cups of milk per day or one pint of milk plus a daily serving of cheese, or ice cream or custard, along with the vegetables, cereals and bread needed to furnish other nutrients will supply these amounts. Plenty of exposure to sunshine or an intake of 400 units of vitamin D each day appear to be appropriate. In order to encourage eating of wide variety of foods it is frequently desirable to restrict the intake of milk to these amounts in the second and third years. Diagrams which are helpful in illustrating the interrelationships of all food items have been given by Butler[25] for preschool children and by Boyd[26] for school children.

The preschool period is one of decreased rate of skeletal growth, of an increased percentage of the body weight in muscle, and of small food intake along with frequent infections. To develop good eating habits during this period one needs to prescribe a variety of foodstuffs high in nutrient values and, usually, to prohibit too much of a single high caloric food.

In the early school years the daily quota of milk should be one quart or its equivalent in the substitutes mentioned above. Minimal daily intakes of calcium have been estimated at around 35 and 25 mg/kg of body weight per day at three and eight years of age respectively.[10]

Higher intakes of calcium and vitamin D during the age period eight to twenty years are being advocated.[13] Calcium intakes of 1.4 to 1.7 g per day accompanied by at least 1,000 units of vitamin D are suggested.[27] A quart and a half of milk each day or substitutes of dairy products are needed to supply this amount of calcium. These estimates of needs are based largely on balance data and exceed the dietary calcium intake of children of similar age in many parts of the world.

TABLE II

Current Estimates of Desirable Intakes of Calcium and Vitamin D

Age group	Estimated need for calcium	Foods (for higher estimated need)	Estimated need for vitamin D
Infancy			
Breast fed	40 mg/kg/day	Human milk	400 u. vit. D.
Artificial feedings	70–120 mg/kg/day	$^2/_3$ of calories from cow's milk	400 u. vit. D.
Preschool	0.5–0.8 g/day	3 cups of milk or equivalents of cheese, ice cream, custards, plus vegetables, cereals, bread	None to 400 u. vit. D.
6–8 years	0.7–1.0 g/day	1 quart of milk or equivalents plus vegetables, cereals, bread	?added vit. D.
Peri-puberty 9–18 years	1.0–1.5 g/day*	$1^1/_2$ quarts of milk or equivalents plus vegetables, cereals, bread	?800–?3,000 u. vit. D.

* Possibly larger than necessary (see text).

The evidence that these smaller intakes are detrimental is not substantial. Thus it may be that the amounts of calcium traditionally recommended in this country are unnecessarily generous. More data is clearly required in this age period.

The period preceeding, during and following puberty is apparently one of nutritional stress; one of wide fluctuations in protein and mineral balances, without much understanding of the causes or their significance. Minimal requirements have been placed as low as 7 mg/kg of body weight per day for young adults.[10] Excessive intakes or intestinal absorption of calcium are seldom encountered except where milk and cream diets with alkalis are prescribed[13] or larger than usual amounts of vitamin D are ingested, especially by infants unusually sensitive to vitamin D.[28]

The current estimates of calcium intakes for good health are summarized in Table II.

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