Influence of Diet on Acid-Base Balance

Thomas Remer
Research Institute of Child Nutrition, Dortmund, Germany

ABSTRACT

It is well established that diet and certain food components have a clear impact on acid-base balance. For adults, the following factors are involved: 1) the chemical composition of foods (i.e., their content of protein, chloride, phosphorus, sodium, potassium, calcium, and magnesium), 2) the different intestinal absorption rates of the relevant nutrients, 3) the metabolic generation of sulfate from sulfur-containing amino acids, 4) the grade of dissociation of phosphorus at the physiologic pH of 7.4, and 5) the ionic valence of calcium and magnesium. All these factors allow us to estimate the potential renal acid load (PRAL) of any given food or diet. The PRAL (calculated for a 24-hour period), together with a relatively constant daily amount of urinary excreted organic acids (in healthy subjects proportional to body surface area or body weight), yields the daily net acid excretion. This article provides an overview of the current concepts of diet influences on acid-base balance and also focuses on the underlying physiologic and biochemical basis as well as on relevant clinical implications.

It has been known for a long time that the composition of the diet can strongly affect acid-base balance. Early in the 20th century researchers began to test the hypothesis that the sum of the chloride, phosphorus, and sulfur content of a given food determines its acid-forming potential, whereas the base-forming potential is derived from the sum of sodium, potassium, calcium, and magnesium in that food (1). Sherman and Gettler (1) published an extensive list of the mineral and acid-base contents of various foods. In one of the first balance experiments (2) on two normal infants the concept of Sherman and Gettler—later known as the dietary ash hypothesis—allowed a rough estimation of the measured acid excretion. Since then this concept of diet-dependent acid-base balance has undergone several modifications. In the last decades the grade of dissociation of phosphorus (i.e., phosphate) at a physiologic pH of 7.4 has also been considered (3, 4), and it became clear that endogenous production and excretion of organic acids had to be taken into account (3, 5). The current concept also takes into account different intestinal absorption rates of individual nutrients (6–9) in addition to chemical composition of foods, sulfate production from metabolized proteins, grade of dissociation of phosphorus, and urinary excretion of organic acids. This article provides an overview of the current concepts of diet influences on acid-base balance emphasizing basic physiologic aspects.

Address correspondence to: Thomas Remer, MD, Forschungsinstitut fuer Kinderernaehrung, Heinstueck 11, 44225 Dortmund, Germany. E-mail: remer@fke.uni-dortmund.de.

Seminars in Dialysis—Vol 13, No 4 (July-August) 2000 pp. 221-226

Basic Physiologic Aspects

Fig.1 shows the interaction of the different organs in acid-base metabolism. Although the importance of gastrointestinal absorption of nutrients and other dietary components in determining acid production was recognized decades ago, the role of the intestine has not received much attention in the scientific literature. Fig. 1 indicates schematically that the intestine is directly involved in acid and/or base generation and consequently must be considered as an acid- or base-forming organ. Furthermore, the liver, in particular, produces large amounts of hydrogen ions and alkali ions by oxidizing the absorbed sulfur-containing amino acids and a number of organic anions, respectively. Initially these ions are buffered by intracellular fluid buffers. Then after release from the respective cells into circulation they add to the diet-derived acid-base pool in blood (Fig. 1), which is buffered by extracellular fluid buffers as well as by pulmonary mechanisms before the kidneys excrete the ions to maintain balance.

The lungs maintain the blood pH within a narrow range by altering the rate at which CO_2 is excreted in proportion to the actual alteration in the blood bicarbonate level (respiratory compensation). Even though the lungs can maintain or modify pH by changing the partial pressure of CO_2 (pCO_2), this process cannot cause any loss or gain in hydrogen ions (10). The lungs are incapable of regenerating lost bicarbonate. This is one important task of the kidneys. The other is the elimination of an amount of acid equal to the endogenously produced and/or diet-derived nonvolatile acids (Fig. 1).

According to the traditional dietary ash hypothesis, foods containing an excess of inorganic or fixed anions (Cl, P, S) over inorganic or fixed cations (Na, K, Mg, Ca)

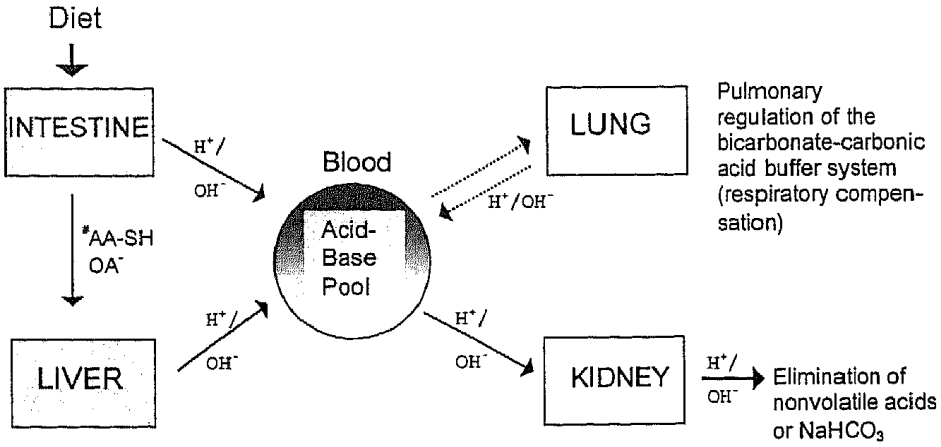

FIG. 1. Interaction of organs in acid-base metabolism (H^+, hydrogen ions; OH^-, primarily HCO_3-); #AA-SH = sulfur-containing amino acids, OA^- = alkali salts of nonmetabolizable organic acids.

are said to have acidifying properties. Conversely an excess of inorganic cations over inorganic anions should result in a relative increase in alkalinity, implying that equal amounts of inorganic anions and cations in food show no relevant effect on acid-base balance. However, this is not necessarily true in vivo because the intestinal absorption rates vary considerably for individual nutrients (and ions). For example, intestinal absorption of calcium (25–40%) is less than half that of most inorganic anions. If calcium absorption is assumed to be 25% and calcium is ingested in the form of its chloride salt (4 mmol = 8 mEq) then an excess of chloride over calcium of nearly 6 mEq (chloride absorption 95%) enters the intestinal cells and blood (Fig. 2). The portion of calcium (6 mEq) not absorbed reacts with bicarbonate secreted by the pancreas and is excreted in the stool. Since the sodium from the pancreatic secretion is reabsorbed as NaCl (which is neither an acid nor a base) and not as $NaHCO_3$ (which is a base), a net loss of base equivalents occurs. Thus $CaCl_2$ is an acidifying agent when given orally (11).

Conversely, the ingestion of $NaHCO_3$ has a strong alkalizing effect as a result of complete absorption of sodium as NaCl. The corresponding chlorine derives from gastric hydrochloric acid secretion. Since the removal of the protons secreted by the stomach is unmatched by a loss of endogenously derived base, a net loss of acid (i.e., an alkalizing effect) occurs. Consequently, the extent of the bioavailability of individual nutrients (minerals and protein), that is, intestinal absorption rates, plays an important role in acid or base generation in vivo.

The other major acid- or base-generating organ is the liver. In a metabolic steady state the same amount of sulfur-containing amino acids (AA-SH) that has been absorbed from the diet and a large part of the absorbed alkali salts of metabolizable organic acids are oxidized by this central organ yielding acid (H_2SO_4) and base (e.g., $NaHCO_3$), respectively (Fig. 3).

After entering the blood the sulfuric acid from hepatic AA-SH oxidation is buffered by bicarbonate, with the

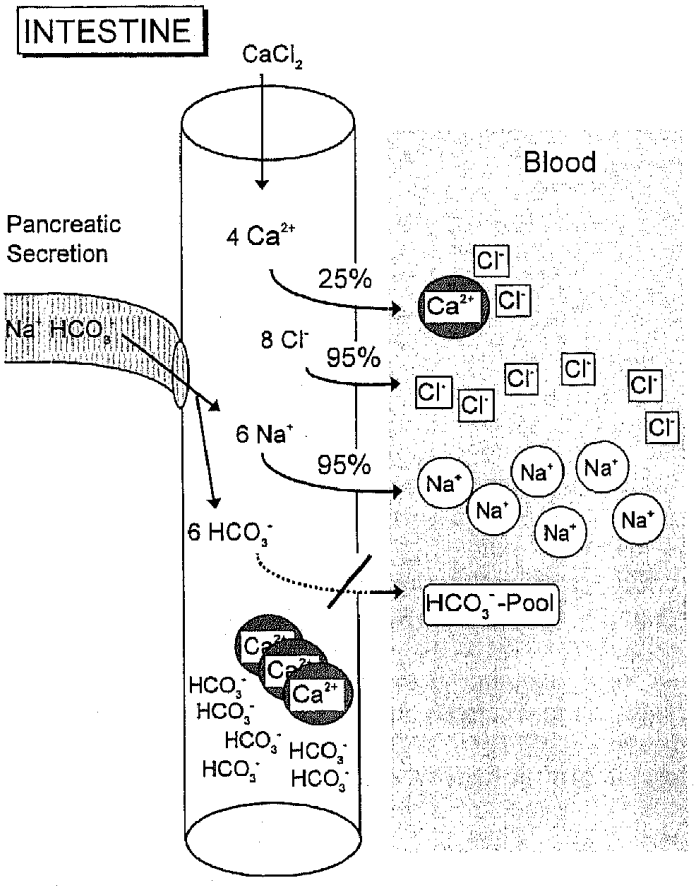

FIG. 2. The intestine as an acid- or base-forming organ. Here, an example of the generation of net acid as a result of a physiologically low cation (Ca) absorption and an associated loss of endogenous HCO_3-.

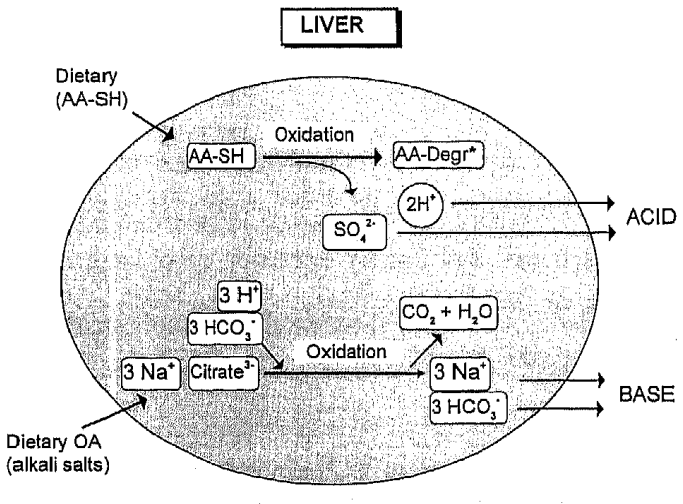

FIG. 3. Contribution of hepatic metabolism of sulfur-containing amino acids (AA-SH) and metabolizable organic acids (OA) in the formation of acid and base.

generation of neutral Na_2SO_4 and carbonic acid (Fig. 4). The latter is eliminated as CO_2 by the lung (respiratory compensation). The neutral salt, Na_2SO_4, is transported to the kidney and the sodium is reabsorbed for the restoration of the circulating bicarbonate pool (Fig. 4). An active renal hydrogen ion secretion through a H^+/Na^+ antiporter transport protein drives this process in the distal renal tubular duct or collecting duct cell (10). Since the kidney cannot elaborate urine more acid than pH 4.4, only negligible quantities of strong acids, such as sulfuric acid, can be eliminated in free titratable form. Consequently appropriate hydrogen ion acceptors must buffer most of the secreted hydrogen ions.

One such important buffer is ammonia (NH_3, see Fig. 4). It is synthesized in proximal tubular cells from the deamidation and deamination of glutamine in the presence of glutaminase (10). Ammonia diffuses through the lipid membrane of the cells into the tubular fluid, where it reacts with hydrogen ions to form ammonium (NH_4^+). This charged cation cannot readily diffuse back from the luminal fluid. Consequently the sulfuric acid derived from hepatic oxidation of dietary protein-derived amino acids is excreted primarily as $(NH_4^+)_2SO_4^{2-}$ (Fig. 4.).

Recently we were able to show that increased protein intake significantly improves renal net acid excretion by increasing urinary ammonium output at any given urine pH (12). This is shown in Fig. 5. The data represent a synopsis of three different studies (7, 12, 13). When the urine pH was adjusted at a level of about 6.7 in healthy subjects ingesting either 50 g/day or 82 g/day of protein, then a given (constant) acid load was excreted at two significantly different ammonium excretion rates [Fig. 5, study 3 (12)]. The urinary ammonia output was higher with the higher protein intake. The pH adjustment was achieved by administration of sodium citrate along with the 82 g protein diet.

Correspondingly, subjects on a high protein intake (120 g/day) could eliminate their high acid load at a given low urine pH of about 5.5 with a significantly higher renal ammonia excretion than on a lower protein intake (95 g/day) during which the urine pH was adjusted to approximately 5.5 by L-methionine administration [Fig. 5, study 1 (7)]. In agreement with the above data

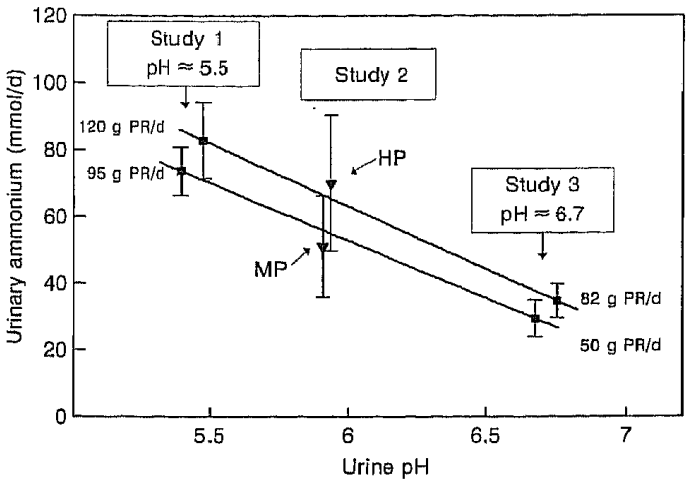

FIG. 5. Dependency of urinary ammonium excretion on urine pH at different protein intake levels (PR/d = protein intake/day; studies 1–3, see text).

from controlled diet experiments we also found an elevated ammonium excretion at a fixed urine pH in association with a higher protein intake in a cross-sectional study after the subjects were assigned to a high protein (HP) and a moderately high protein (MP) group according to the median of their protein intake [Fig. 5, study 2 (13)]. The average values for urinary ammonium excretion and urine pH of the latter subjects who were on ad libitum diets (study 2) fitted surprisingly well with the regression lines given by experimental studies 1 and 2 (Fig. 5). Thus it can be concluded that the renal capacity to excrete excess acid as ammonium is clearly increased by an increase in protein intake, and this is the case for any given urine pH, that is, for any given stimulus of renal ammoniagenesis. Such a diet-related adaptation mechanism is physiologically meaningful because it allows us to better cope with extreme variations in renal acid loads, which are often caused by marked variations in protein intake.

The clear association between urine pH and urinary ammonium excretion seen in Fig. 5 is a direct reflection of the strong relationship that exists between total renal net acid excretion (NAE) and urine pH. NAE is the sum of titratable acid and ammonium minus the bicarbonate

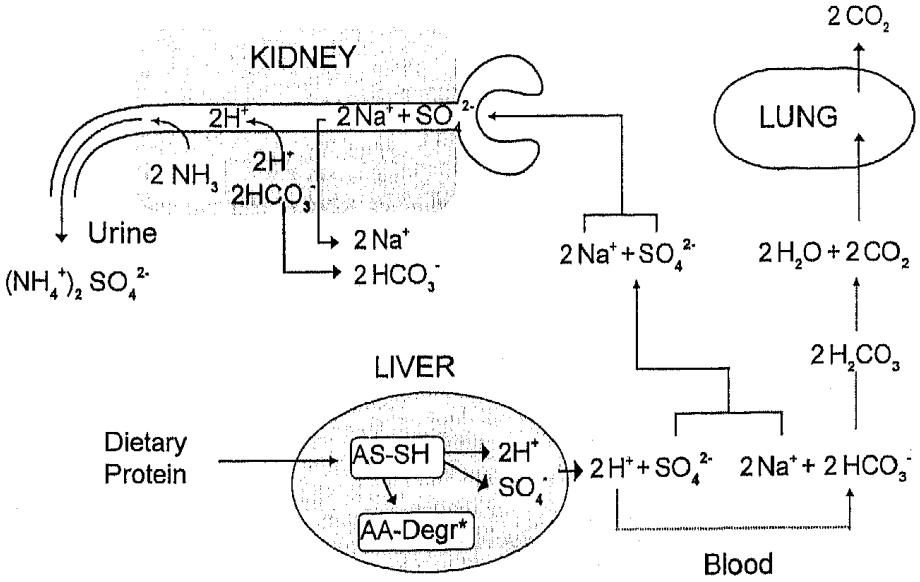

FIG. 4. Hepatic generation, intermediary buffering, and renal excretion of acid equivalents.

urinary excretion rate (Fig. 6). Measurements of urine pH and NAE in healthy adults consuming various normal mixed diets have shown average urine pH values of 6.7, 6.3, 5.9, and 5.6 for NAE ranges of 0–40, 40–80, 80–120, and 120–160 mEq/day, respectively (8). Up to 70% of the variability in urine pH can be explained by variations in NAE in normal subjects, and the NAE itself is strongly influenced by the diet. Recent methodologic efforts have been successful in providing reasonable estimates of NAE produced by diets.

Model for the Estimation of Dietary Effects on NAE and the Potential Renal Acid Load of Food

A physiologically based calculation model that corrects for intestinal absorption of individual minerals and sulfur-containing protein and assumes a rate of urinary excretion of organic acids proportional to body surface area (or body mass) was tested for its applicability to predict the NAE of adults (7). The model makes use of the fact that all three elements which determine NAE (NH_4, TA, HCO_3) are components of the normal urine ionogram (Fig. 6). Thus the NAE could be indirectly determined from the difference of the sum of the nonbicarbonate anions minus the sum of the mineral cations [i.e., NAE indirect = (Cl + P + SO_4 + organic acids) – (Na + K + Ca + Mg)] excreted in urine. Urinary excretion rates of SO_4 and all minerals were estimated from daily nutrient intake data (according to current food composition tables) by using published average intestinal net absorption rates for protein (75%), phosphorus (63%), chloride (95%), sodium (95%), potassium (80%), calcium (25%), and magnesium (32%) (for literature, see Refs. 7 and 8). For calcium and magnesium, the ionic valence (×2), and for phosphorus the grade of dissociation of pH 7.4 (×1.8) were also considered. For total protein, an average content of 2.4% methionine and 2% cysteine was assumed (7, 8). Renal organic acid excretion has been estimated to be 41 mEq/day/1.73 m^2 (14).

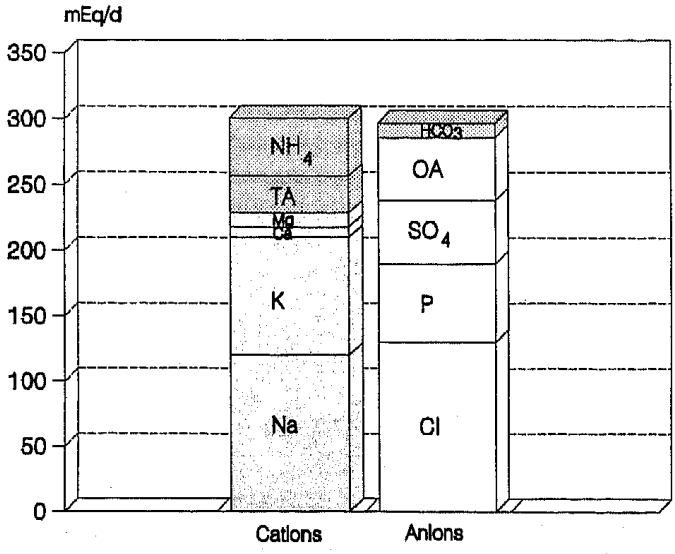

FIG. 6. Typical urine ionogram—with all quantitatively important urinary anions and cations—of a healthy adult consuming a protein-rich mixed diet. (NH_4 = ammonium; TA = titratable acid; Mg = magnesium; Ca = calcium; K = potassium; Na = sodium; HCO_3 = bicarbonate; OA = organic acids; SO_4 = sulfate; P = phosphorus; Cl = chloride. The directly analyzed net acid excretion (NAE_{direct}) equals TA + NH_4 – HCO_3. Consequently the indirectly determined net acid excretion corresponds to the sum of the nonbicarbonate anions minus the sum of the mineral cations [$NAE_{indirect}$ = (Cl + P + SO_4 + OA) – (Na + K + Ca + Mg).

In a controlled diet study encompassing four separate 5-day diet periods healthy adults ingested four nearly isoenergetic diets (one lactovegetarian and one high- and two moderate-protein diets) and collected 24-hour urine samples at the end of each test period. Based on the above methodologic approach, the diets were estimated to yield NAE values ranging from a minimum of 4 to a maximum of 118 mEq/day (Fig. 7). The analytically determined NAE corresponded reasonably well to these estimates (Fig. 7), suggesting that the calculation model has been appropriate to predict the renal NAE from nutrient intake and anthropometric data. Fig. 8 shows the corresponding values for urine pH. All these findings provide evidence that adjustments or specific manipulations of urinary pH and NAE in response to changes in dietary intake are possible.

On the basis of these findings and earlier studies on protein hydrolysates (5), synthetic amino acid mixtures (5), and milk formulas (6, 15)—each confirming the applicability of the calculation model—it appeared possible and useful to estimate the potential renal acid load (PRAL) of foods. For this, the average absorbable amounts of all relevant nutrients/ions of which urinary excretion is obligatory were calculated for selected, frequently consumed foods and beverages using nutrient data from actual food composition tables and average net absorption rates from literature (as mentioned above). Before adding the anions (Cl, P, SO_4) and subtracting the cations (Na, K, Ca, Mg) for each food (per 100 g edible portion) the specific values for ionic valence, grade of dissociation, and average content of sulfur-containing amino acids—as given above—were also considered. This difference in the sum of anions and the sum of cations corresponds to the NAE indirect without organic acids (see Fig. 6). The calculation model yielded PRAL values ranging from a maximum of 34.2 mEq/100 g (parmesan cheese) over 0 mEq/100 g for fat and oils to a minimum of –21 mEq/100 g (raisins) (8). Fruits and vegetables have negative PRAL values, meaning they

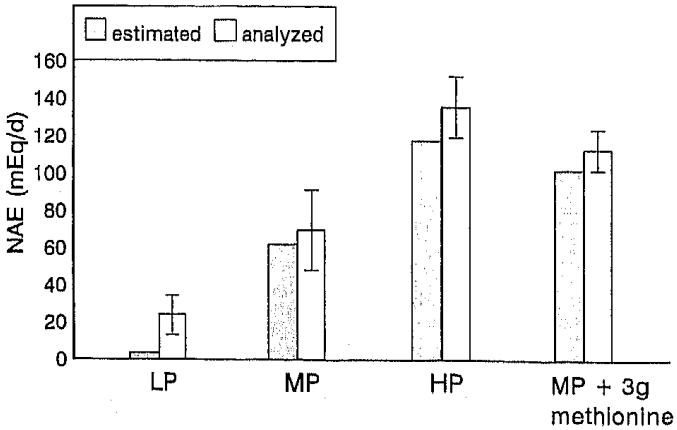

FIG. 7. Estimated and analyzed net acid excretion (NAE) with one lactovegetarian low-protein (LP), one high-protein (HP), and two moderate-protein (MP) diets.

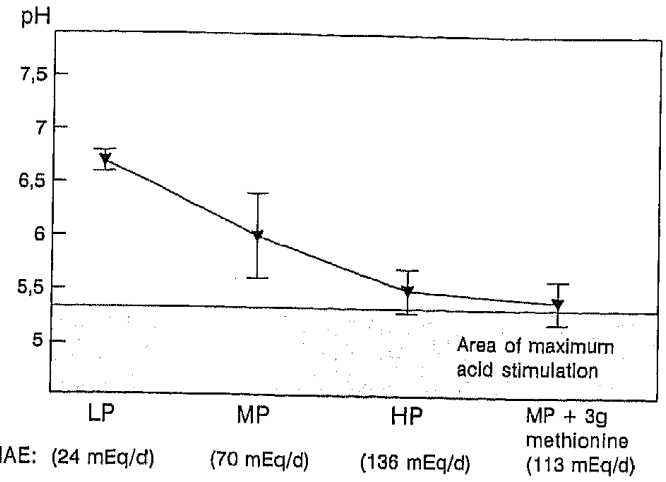

FIG. 8. Urine pH values with the four diets for which estimated and analyzed net acid excretion is shown in Fig. 7.

reduce acid excretion. Milk and yogurt yield about 1 mEq, whereas meat, fish, poultry, cheese, and even some grain products potentially yield 7 mEq or more acid per 100 g serving. This can also be seen in Table 1, which presents average PRAL values of certain groups and subgroups of foods.

Table 2, an example of an extremely simplified diet, indicates that the exchange of only a few (at least moderately) protein-rich foods to alkali-rich foods can markedly alter the daily intake of acid equivalents. Table 2 also demonstrates that the renal NAE is not affected solely by food-dependent acid loads but also by an important individual factor: the daily excretion rates of organic acids. The association between urine pH and renal NAE as observed in healthy subjects (8) is correspondingly reflected in the data of Fig. 8, indicating that consumption of diets with an estimated renal NAE of about 100 mEq ("diet A" in Table 2) and about 40 mEq ("diet B" in Table 2) should result in average 24-hour urine pH levels of less than 6 and more than 6.5, respectively. In other words, diets yielding daily PRAL values of approximately 0 mEq/day or less (as "diet B") produce a clearly higher urinary pH than diets having, for example, a daily PRAL of about 60 mEq/day (as the fictitious diet A).

TABLE 1. Average potential renal acid loads (PRAL)[a] of certain food groups and combined foods (related to 100 g edible portion)

Food group	PRAL (mEq)
Beverages	
Alkali-rich and low phosphorus[b]	−1.7
Alkali-poor and low phosphorus[c]	0
Fats and oils	0
Fish	7.9
Fruits and fruit juices[d]	−3.1
Grain products[e]	
Bread	3.5
Flour	7.0
Noodles, spaghetti	6.7
Meat and meat products	9.5
Milk and dairy products	
Milk and noncheese products[f]	1.0
Cheeses with lower protein content[g]	8.0
Cheeses with higher protein content[h]	23.6
Vegetables[i]	−2.8
Potatoes	−4.0

[a] Data represent the arithmetic means of the PRAL values of the respective foods [Table 1 (8)].

[b] Beverages (phosphorus < 30 mg/100 g) with several times higher sodium + potassium content compared to chloride, for example, red wine, white wine, certain mineral (soda) waters and coffee.

[c] Beverages (phosphorus < 30 mg/100 g) with similar sodium + potassium versus chloride content. Cocoa (alkali and phosphorus rich) also falls in this PRAL category. Because of a medium phosphorus content (e.g., 28 mg/100 g) European pale beers (e.g., "Pils") have a relative high PRAL value (about 1 mEq/100 g).

[d] Without dried fruits.

[e] Irrespective of the type of flour (whole meal or white, plain).

[f] Primarily whey based.

[g] Less than 15 g protein/100 g.

[h] More than 15 g protein/100 g.

[i] Without asparagus (very low alkali excess) and spinach (very high alkali excess).

Implications

Based on the model for the estimation of dietary effects on NAE presented herein, which considers mean intestinal absorption rates for individual nutrients and postabsorptive metabolism of sulfur-containing amino acids, it is possible to estimate the diet-dependent component of daily renal NAE, that is, the daily PRAL. Another NAE component, the excretion of organic acids, which depends primarily on body weight (or body surface area) and is relatively constant for each individual, must also be considered to yield the total NAE that determines each person's urine pH level. Because urine pH is a relevant risk factor in most types of urinary stone disease, a dietetic manipulation of renal hydrogen ion excretion would be advantageous for a number of individuals at risk. Also, patients with poorly functioning kidneys—in whom metabolic acidosis is a common manifestation of an impaired renal capacity to excrete the daily produced acid—could benefit from specific dietetic means that reduce daily acid load.

In addition, diets high in protein can cause excessive urinary calcium losses because of their acid content (16). Apart from calcium intake, calciuria is directly related to urinary net acid excretion and not to protein intake per se (16, 17). This was also observed in our controlled diet study (of which NAE and urinary pH are shown in Figs. 7 and 8). Fig. 9 shows that calciuria was significantly increased after a constant moderately protein-rich diet was ingested for a second time added only with 3 g of L-methionine. The increase in urinary calcium loss of almost 1 mmol/day (nearly 40 mg/day) occurred in parallel with increases in urinary sulfate output and urinary NAE of about 40 mEq/day each. According to Barzel and Massey (16) the scientific evidence now available leaves little doubt that excess acidity will create a reduction in total bone substance. Thus there is clearly more than one reason why the evaluation of the acid-base effect of a diet is a useful tool in preventive nutritional medicine.

However, it has to be kept in mind that there are a number of sources of inaccuracies and variations involved in predicting urinary NAE (and urine pH) because such predictions require accurate knowledge of the components of all meals and their respective weights as well as reliable data on the nutrient composition of the

TABLE 2. Estimation of daily renal net acid excretion (NAE) for a woman[a] consuming a fictitious diet with a relatively high (diet A) or low (diet B) potential renal acid load (PRAL)

Diet A					Diet B				
Food	Intake, *g/day*	Energy, *kcal/day*	Protein, *g/day*	PRAL,[b] *mEq/day* (mEq/100 g)	Food	Intake, *g/day*	Energy, *kcal/day*	Protein, *g/day*	PRAL,[b] *mEq/day* (mEq/100 g)
Bread, wheat flour	200	466	12.4	7.0 (3.5)	Bread, wheat flour	200	466	12.4	7.0 (3.5)
Turkey	200	214	43.8	19.0 (9.5)	Turkey	200	214	43.8	19.0 (9.5)
Cottage cheese	350	343	48.3	28.0 (8.0)	Tomatoes and carrots	500	116	3.1	−14.0 (−2.8)
Spaghetti	120	410	14.4	8.0 (6.7)	Potatoes	400	300	8.4	−16.0 (−4.0)
Butter, margarine	102	753	0.4	0.0 (0.0)	Butter, margarine	147	1,085	0.5	0.0 (0.0)
		≈2,200	119.3	62.0			≈2,200	68.2	−4.0
Daily urinary excretion of organic acids[a,c]				41.6[a]					41.6[a]
Daily NAE (estimated)				103.6					37.6

[a] An adult female 63 kg in weight and 163 cm in height.
[b] PRAL values taken from Table 1.
[c] Simplified estimation of daily excretion of organic acids (OA) using individual body weight (BW) (14): OA (mEq/day) = BW × 0.66.

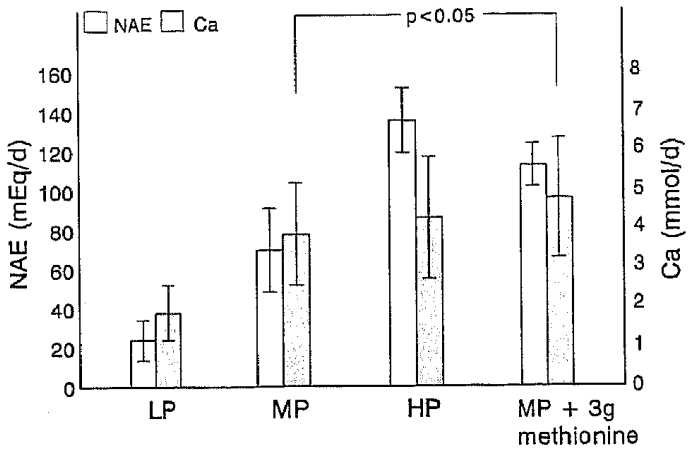

FIG. 9. Urinary calcium excretion with the four diets characterized in Figs. 7 and 8. Calcium intake was similar with all diets (and identical for diets MP and MP + 3 g methionine).

ingested foods. Inherent nutrient variations of natural foods and different kinds of food processing and preparation can be a problem, as well as considerably varying nutrient absorption rates between individuals. Furthermore, the present calculation model requires a certain metabolic steady state, that is, a constancy of nutrient intake for at least 2–3 days. Consequently no adequate estimation of actual NAE appears possible if clear day-to-day variations in dietary nutrient intake are present. Barzel and Massey (16) recently argued that there is a need to develop more convenient methods for quantitating urinary acid excretion. Whether a simplified approach to predict NAE, for example, the dietary protein:potassium ratio (18, 19) could be an acceptable tool deserves further research.

References

1. Sherman HC, Gettler AO: The balance of acid-forming and base-forming elements in foods, and its relation to ammonia metabolism. *J Biol Chem* 11:323–328, 1912
2. Shohl AT, Sato A: Acid-base metabolism. 1. Determination of base balance. *J Biol Chem* 58:235–239, 1923
3. Gonick HC, Goldberg G, Mulcare D: Reexamination of the acid-ash content of several diets. *Am J Clin Nutr* 21:898–903, 1968
4. Dwyer J, Foulkes E, Evans M, Ausman L: Acid/alkaline ash diets: time for assessment and change. *J Am Diet Assoc* 85:841–845, 1985
5. Manz F, Schmidt H, Schärer K, Bickel H: Acid-base status in dietary treatment of phenylketonuria. *Pediatr Res* 11:1084–1087, 1977
6. Manz F, Schmidt H: Retrospective approach to explain growth retardation and urolithiasis in a child with long-term nutritional acid loading. *Z Ernährungswiss* 31:121–129, 1992
7. Remer T, Manz F: Estimation of the renal net acid excretion by adults consuming diets containing variable amounts of protein. *Am J Clin Nutr* 59:1356–1361, 1994
8. Remer T, Manz F: Potential renal acid load of foods and its influence on urine pH. *J Am Diet Assoc* 95:791–797, 1995
9. Manz F, Kalhoff H, Remer T: Renal acid excretion in early infancy. *Pediatr Nephrol* 11:231–243, 1997
10. Adelman RD, Solhaug MJ: Hydrogen ion (acid-base balance), in *Nelson Textbook of Pediatrics*, 15th edn, edited by Behrman RE, Kliegman RM, Arvin AM, Philadelphia, WB Saunders, 1996, pp. 200–206
11. Brewer ED: Disorders of acid-base balance. *Pediatr Clin N Am* 37:429–447, 1990
12. Remer T, Manz F: Dietary protein as a modulator of the renal net acid excretion capacity: evidence that an increased protein intake improves the capability of the kidney to excrete ammonium. *J Nutr Biochem* 6:431–437, 1995
13. Manz F, Remer T, Decher-Spliethoff E, et al: Effects of a high protein intake on renal acid excretion in bodybuilders. *Z Ernährungswiss* 34:10–15, 1995
14. Manz F, Vecsei P, Wesch H: Renale Säureausscheidung und renale Molenlast bei gesunden Kindern und Erwachsenen. *Monatsschr Kinderheilkd* 132: 163–167, 1984
15. Kalhoff H, Manz F, Diekmann L, Stock GJ: Suboptimal mineral composition of cow's milk formulas: a risk factor for the development of late metabolic acidosis. *Acta Paediatr Scand* 79:743–749, 1990
16. Barzel US, Massey LK: Excess dietary protein can adversely affect bone. *J Nutr* 128:1051–1053, 1998
17. Sebastian A, Harris ST, Ottaway JH, Todd KM, Morris RC: Improved mineral balance and skeletal metabolism in postmenopausal women treated with potassium bicarbonate. *N Engl J Med* 330:1776–1781, 1994
18. Frassetto L, Todd K, Morris RC Jr, Sebastian A: Estimation of net endogenous acid production in humans from diet potassium and protein content. *Nephrology* 3:S341A, 1997
19. Lemann J Jr: Relationship between urinary calcium and net acid excretion as determined by dietary protein and potassium: a review. *Nephron* 81:S18–S25, 1999