Effect of dietary macronutrient content on carnitine excretion and efficiency of carnitine reabsorption[1–3]

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ABSTRACT We examined the effect of macronutrient content on glomerular filtration rate (GFR), and excretion, reabsorption, and filtered load of carnitine. Ten subjects consumed five diets [high protein (HP), low protein (LP), control, high fat (HF), and high carbohydrate (HC)] of equal energy and carnitine content for 6 d each, in a randomized crossover manner. The rate of carnitine excretion was lower after the LP diet than after the HP diet because of lower GFR after the LP diet. The rate of carnitine reabsorption was lower after the LP diet than after the HP diet, also because of the lower GFR after the LP diet. The rate of carnitine reabsorption was not different after the HF and HC diets, nor was GFR. The filtered load of carnitine, however, was greater after the HF diet, resulting in a higher rate of carnitine excretion. *Am J Clin Nutr* 1993;58:868–72.

KEY WORDS Carnitine reabsorption, urinary carnitine excretion, glomerular filtration rate, diet, macronutrient composition

Introduction

Carnitine, a naturally occurring compound found in humans and other mammals, facilitates the transport of long-chain fatty acids into the mitochondria for adenosine triphosphate (ATP) production via β-oxidation and oxidative phosphorylation. Carnitine also functions to remove from the mitochondria short- and medium-chain organic acid products of metabolism. Carnitine is synthesized in the liver and kidney in humans from the essential amino acids lysine and methionine. Carnitine is also obtained exogenously from the diet almost exclusively from foods of animal origin. Between 54% and 87% of dietary carnitine is absorbed depending on the amount of carnitine ingested (1). The kidney, in addition, contributes to carnitine homeostasis as the site of carnitine reabsorption. At normal plasma carnitine concentrations, > 84% of filtered carnitine is reabsorbed (2).

In humans, plasma carnitine concentration and urinary carnitine excretion are affected by the macronutrient content of the diet. High-fat diets result in higher plasma carnitine concentrations and higher carnitine clearances than do low-fat diets (3). Among individuals consuming vegetarian diets, which tend to be high in carbohydrate and low in fat, plasma carnitine concentration and urinary carnitine excretion are significantly lower compared with individuals consuming omnivorous diets (4). These observations suggested to us that the efficiency of carnitine reabsorption may be affected by the macronutrient composition of the diet. To explore the mechanisms of this phenomenon we examined the effect of dietary macronutrient content on glomerular filtration rate (GFR), and excretion, reabsorption, and filtered load of carnitine.

Methods

General design

Eleven adults, 7 males and 4 females, were recruited from the Iowa City community to participate in a randomized crossover study of the effect of dietary macronutrient content on carnitine reabsorption. Subjects were judged to be healthy after review of their medical histories and physical examination. Exclusion criteria used to screen potential participants included chronic use of medication (including oral contraceptives) and history of renal and/or hepatic disease, diabetes, and abnormal blood pressure. Characteristics of 10 subjects who completed the study are provided in **Table 1.** During the study, subjects consumed five diets of varied protein, fat, and carbohydrate contents. Each diet was consumed for 6 d. Diet order was randomized by using a Latin square model.

Participants consumed self-selected diets before and between controlled diet periods. Time duration between the end of one controlled diet period until the beginning of the next period was between 1 and 31 d. These between-diet periods were provided for the convenience of the participants and/or to meet scheduling requirements of the Clinical Research Center (CRC). No washout period between controlled diets was necessary or intended in this protocol. Fasting blood samples were obtained at baseline (day 0), and on days 2, 4, and 6 of each diet period. Body-weight measurements and urine samples from 24-h urine composites were obtained daily. GFR (estimated from clearance of inulin) and clearance of carnitine, creatinine, uric acid, and phosphate were measured on the day after each diet period (day 6).

Written consent was obtained from each subject before entry into the study. The research protocol was reviewed and approved by the University of Iowa Committee on Research Involving Hu-

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TABLE 1
Subject characteristics*

	Male (n = 6)	Female (n = 4)	Total
Age (y)	27 ± 2	29 ± 1	28 ± 2
Weight (kg)	75 ± 7	55 ± 9	67 ± 13
Height (cm)	176 ± 5	161 ± 6	170 ± 9
Body surface area (m^2)	1.92 ± 0.12	1.58 ± 0.14	1.78 ± 0.22

* $\bar{x}$ ± SD.

man Subjects and the General Clinical Research Center Protocol Review Committee before the start of the study.

Diets

Five diets (low protein, high protein, control, high fat, and high carbohydrate) were designed to be isoenergetic and to contain equal amounts of carnitine, sodium, potassium, phosphorus, calcium, and cholesterol, and a similar ratio of polyunsaturated to saturated fatty acids (**Table 2**). By design, fat and carbohydrate contents of the low-protein, high-protein, and control diets were 46% and 54%, respectively, of nonprotein energy. Each dietary treatment consisted of one menu repeated daily. As much as possible, each menu contained similar foods but in varying amounts. Major sources of carnitine were ground beef, tuna, chicken, turkey, and milk. The quantity of food provided to each subject was determined by the subject's estimated energy requirement to maintain body weight based on height, weight, age, sex, and usual physical activity (8). All meals were prepared and administered by the dietary staff of the CRC. Each subject was to consume all of the food provided and only that food. Subjects were judged to be compliant by direct observation of meals eaten in the CRC and by questioning the subjects about food consumed while away from the CRC.

Measurement of glomerular filtration rate

The day GFR and solute clearances were measured, each subject was admitted as an outpatient to the CRC at 0700. A light breakfast (toast with jelly) and two glasses (240 mL each) of orange juice and/or water were consumed. Two intravenous catheters with heparin locks were placed, one in each forearm—one to infuse inulin and the other to obtain blood samples. Subjects then voided their bladders and heparinized blood samples were obtained. Inulin (sterile, diluted to 50 mL with 0.45% NaCl; Iso-Tex Diagnostics, Friendswood, TX) was infused initially as a bolus over 10 min to obtain a plasma concentration of ≈ 50 μmol/L (assumption: average molecular weight of inulin is 5000 g/mol). A continuous sustaining infusion of inulin was then initiated to maintain a constant plasma inulin concentration at ≈ 50 μmol/L for the duration of the study. Blood samples and complete urine collections were obtained six times during the clearance study: before the inulin infusion, after a 45-min equilibration period after infusion of the inulin bolus, and every 30 min thereafter for 120 min. A urine flow rate between 3 and 10 mL/min was maintained by having the subject drink 120–240 mL water within each 30-min sampling interval, as necessary.

Plasma and urine analyses

Plasma and urine samples were analyzed for free and total (free plus esterified) carnitine as described previously (2), except that for total carnitine determination, acylcarnitine esters were hydrolyzed at 25 °C for 1 h in the presence of 0.1 mol KOH/L. Inulin was measured in plasma and urine by the method of Liedtke and Duarte (9). Creatinine was measured as previously described (10). Phosphorus was measured spectrophotometrically by reaction with ammonium molybdate (11), and uric acid was quantified by the method of Fossati et al (12), but with 4-aminoantipyrene and n-ethyl-n-sulfohydroxypropyl-*m*-toluidine as chromophore precursors. Methods for measurement of phosphorus and uric acid were adapted for automated analysis by using the SBA 300 Clinical Chemistry Analyzer (Gilford Systems, Oberlin, OH).

Before the study, test meals for each dietary treatment were prepared, homogenized, and analyzed for energy by bomb calorimetry. Sodium, potassium, and calcium were determined by atomic absorption spectrophotometry. Total nitrogen was determined as described by Fomon et al (13) and fat was determined by the method of Jeejeebhoy et al (14). Phosphorus was measured by the method of Daly and Ertingshausen (11) and carnitine was measured as previously described (2). Mineral content of the diets was normalized by supplementation where indicated with potassium chloride, sodium chloride, calcium phosphate, phosphoric acid, and dibasic sodium phosphate. Duplicate meals were prepared for each subject once each diet period and analyzed for

TABLE 2
Macronutrient composition and carnitine content of test diets

	Protein		Fat		Carbohydrate		Carnitine content
Diet	Calculated*	Analyzed†	Calculated*	Analyzed†	Calculated*	Analyzed‡	Analyzed†
	% of total energy		*% of total energy*		*% of total energy*		*μmol/kJ*
High protein	35	43 ± 2§	30	29 ± 2	35	28 ± 3	32 ± 4
Low protein	5	6 ± 1	44	44 ± 4	51	49 ± 4	32 ± 6
Control	17	23 ± 3	38	36 ± 3	45	41 ± 3	31 ± 5
High fat	17	23 ± 3	58	54 ± 4	25	24 ± 5	32 ± 5
High carbohydrate	17	22 ± 1	18	19 ± 1	65	58 ± 2	33 ± 5

* Macronutrient content calculated by using data from references 5–7.
† Each diet was analyzed for total nitrogen, total fat, and total carnitine contents as described in the text.
‡ 100% − (% protein + % fat).
§ $\bar{x}$ ± SD.

TABLE 3
Effect of diet on plasma carnitine concentration on day 6*

Diet	Free	Total
	μmol/L	
High protein	37.9 ± 3.2^{ab}	46.7 ± 2.1^{ab}
Low protein	35.5 ± 8.4^{b}	43.3 ± 2.1^{b}
Control	39.6 ± 3.2^{a}	48.2 ± 1.6^{a}
High carbohydrate	35.6 ± 7.3^{b}	42.9 ± 2.5^{b}
High fat	40.3 ± 6.8^{a}	50.3 ± 2.6^{a}

* $\bar{x}$ ± SEM. Within each column, values with different superscript letters are significantly different, $P < 0.05$.

TABLE 4
Effect of diet on urinary carnitine excretion on day 6*

Diet	Free	Total	Free	Total
	mmol/mol creatinine		*μmol/kg body wt*	
High protein	28.4 ± 3.3^{a}	47.4 ± 5.0^{a}	6.0 ± 0.7^{a}	10.0 ± 0.8^{a}
Low protein	9.4 ± 2.1^{b}	22.5 ± 3.6^{bc}	1.4 ± 0.3^{b}	3.4 ± 0.5^{b}
Control	16.3 ± 2.3^{c}	30.6 ± 3.5^{c}	3.3 ± 0.5^{c}	6.3 ± 0.8^{c}
High carbohydrate	6.9 ± 1.4^{b}	15.6 ± 2.0^{b}	1.4 ± 0.3^{b}	3.1 ± 0.5^{b}
High fat	30.2 ± 3.2^{a}	60.2 ± 5.2^{d}	5.6 ± 0.8^{a}	11.2 ± 1.5^{a}

* $\bar{x}$ ± SEM. Within each column, values with different superscript letters are significantly different, $P < 0.01$.

energy, total nitrogen, fat, and carnitine as described above (Table 2). Carbohydrate content (% of total energy) was determined by the difference between 100% and the sum of the percentages of protein and fat.

Calculations and statistical analyses

The following equations were used to calculate GFR (inulin clearance; C_I), carnitine clearance (C_C), carnitine excretion (E_C), and carnitine reabsorption (Tr_C):

$$C_I = (U_I \times V)/P_I$$

$$C_C = (U_C \times V)/P_C$$

$$E_C = 100 \times (U_C \times V)/C_I, \text{ and}$$

$$Tr_C = [(P_C \times C_I) - (U_C \times V)] \times (100/C_I),$$

where U_I and P_I are the urine and plasma concentrations of inulin (μmol/L), respectively; U_C and P_C are the urine carnitine concentration (μmol/L) and average plasma carnitine concentration (μmol/L) at the start and end of each collection period, respectively; and V is the rate of urine flow (mL/min). Creatinine clearance and rates of phosphorus and uric acid reabsorption were calculated similarly.

Repeated-measures analysis of variance was used for statistical analysis (15). Least-significant-difference contrast was used to establish differences among mean values after each diet. Differences were considered significant at $P < 0.05$.

Results

The age range of all participants was 23–30 y. All but two of the participants were within 10% of their ideal body weight for height as assessed by the midpoints of the ranges provided in the 1983 Metropolitan Height and Weight Tables (16). Two female participants were lean, but within 20% of their ideal body weight for height. Of the 11 individuals enrolled into the study, 10 completed all five diet periods. One subject withdrew from the study before completion because of time constraints. No data are reported for this subject. One subject reported adverse affects (influenza-like symptoms including nausea, dizziness, hypersensitivity, and diarrhea) while consuming the high-protein diet. Determination of GFR of another subject was abandoned after the high-protein diet because of poor hydration status. Both subjects completed successfully the high-protein diet periods and determination of GFR and solute clearances at later dates.

The effects of dietary macronutrient content on plasma carnitine concentration are summarized in **Table 3.** Repeated-measures analysis of variance demonstrated a significant effect of macronutrient content on plasma free- and total carnitine concentration. On day 6 of the dietary regime, plasma carnitine concentration was significantly lower ($P < 0.05$) after the high-carbohydrate diet than after either the high-fat or control diets. Plasma carnitine concentration was also lower ($P < 0.05$) after the low-protein diet than after the control diet. There was no difference in plasma carnitine concentration after the low-protein and high-protein diets.

The pattern of carnitine excretion was similar for free and total carnitine whether calculated per mole creatinine or per kilogram body weight (**Table 4**). On day 6 there was a three- to fourfold difference in carnitine excretion between the high-fat and the high-carbohydrate diets ($P < 0.01$) and a two- to threefold difference between the high-protein and low-protein diets ($P < 0.01$). Mean carnitine excretion after each test diet was significantly different from carnitine excretion after the control diet ($P < 0.01$), except for total carnitine excretion (mmol/mol creatinine) after the low-protein diet.

The effects of dietary macronutrient content on GFR and filtered load of carnitine are presented in **Table 5.** GFR corrected for body surface area was higher after the high-protein diet and the control diet than after the low-protein diet ($P < 0.05$). There was no difference in GFR after the high-fat, the high-carbohydrate, or the control diets. Filtered load of carnitine, corrected for differences in GFR, was higher after the high-fat and control diets than after the high-carbohydrate diet ($P < 0.05$). Filtered load of total carnitine was lower after the low-protein diet than after the

TABLE 5
The effect of diet on glomerular filtration rate (GFR) and filtered load of carnitine*

Diet	GFR	Filtered load	
		Free	Total
	mL·min^{-1}·1.73 m^{-2}	*μmol/L GF*	
High protein	122 ± 6^{a}	41.1 ± 1.6^{a}	46.4 ± 1.9^{ab}
Low protein	104 ± 3^{b}	39.3 ± 1.9^{ab}	44.2 ± 1.9^{a}
Control	119 ± 6^{ac}	41.9 ± 1.2^{a}	47.2 ± 1.2^{b}
High carbohydrate	108 ± 3^{bc}	37.9 ± 2.0^{b}	43.5 ± 2.4^{a}
High fat	115 ± 4^{ab}	42.5 ± 1.5^{a}	49.4 ± 2.2^{b}

* $\bar{x}$ ± SEM. GF, glomerular filtrate. Within each column, values with different superscript letters are significantly different, $P < 0.05$.

TABLE 6
Effect of diet on carnitine reabsorption*

Diet	Free	Total	Free	Total
	μmol/min		*μmol/L GF*	
High protein	4.81 ± 0.31[a]	5.32 ± 1.12[a]	38.2 ± 1.4[ab]	42.2 ± 1.6[ab]
Low protein	4.11 ± 0.37[b]	4.62 ± 0.40[b]	37.7 ± 1.7[ab]	42.4 ± 1.8[ab]
Control	4.94 ± 0.46[a]	5.43 ± 1.59[a]	39.7 ± 1.4[a]	43.5 ± 1.4[ab]
High carbohydrate	4.11 ± 0.32[b]	4.62 ± 0.36[b]	36.8 ± 1.9[b]	41.3 ± 2.3[a]
High fat	4.78 ± 0.41[a]	5.38 ± 0.48[a]	39.7 ± 1.4[a]	44.6 ± 2.0[b]

* $\bar{x}$ ± SEM. GF, glomerular filtrate. Within each column, values with different superscript letters are significantly different, $P < 0.05$.

control diet ($P < 0.05$). There was no difference in filtered load of carnitine after the high-protein and low-protein diets.

The rate of carnitine reabsorption expressed as μmol/min (**Table 6**) was higher after the high-protein and high-fat diets than after the low-protein ($P < 0.05$) and high-carbohydrate ($P < 0.05$) diets, respectively. However, when reabsorption was expressed as μmol/L glomerular filtrate, the difference in reabsorption after the high-protein and low-protein diets disappeared. Therefore, the higher rate of carnitine reabsorption after the high-protein diet is accounted for by a higher GFR. Higher GFR also is responsible for the higher rate of carnitine excretion associated with the high-protein diet. On the other hand, the higher rate of carnitine reabsorption after the high-fat diet, compared with the high-carbohydrate diet, remains after GFR is adjusted for and is therefore attributed to a higher filtered load of carnitine. A higher filtered load of carnitine after the high-fat diet also explains the higher rate of carnitine excretion.

Discussion

Fat and carbohydrate compositions of the diet are known to influence plasma carnitine concentration and urinary excretion of carnitine in humans (3). No studies have been reported that describe the effect of high- or low-protein diets on carnitine status. However, it is well-established that high-protein diets increase GFR and low-protein diets decrease GFR compared with diets of moderate protein content (17). To explore the mechanisms by which macronutrient composition affects carnitine status, we determined GFR, and excretion, reabsorption, and filtered load of carnitine after consumption of diets different in macronutrient composition. We observed higher rates of carnitine reabsorption after the high-protein and high-fat diets than after the low-protein and high-carbohydrate diets, respectively. The higher rate of carnitine reabsorption after the high-protein diet likely is due to higher GFR associated with the high-protein diet. The higher rate of carnitine reabsorption after the high-fat diet, compared with the high-carbohydrate diet, was associated with a higher filtered load of carnitine. Filtered load of carnitine, however, was not elevated as a result of increased GFR, but rather as a result of increased plasma carnitine concentration.

To determine whether the trends we observed were specific for carnitine, or whether they were generalized phenomena, we measured and calculated the same indexes for two other solutes: phosphate and uric acid. Phosphate, like carnitine, is reabsorbed by a sodium-gradient-dependent-cotransport system (18) and was therefore chosen as a positive control for carnitine reabsorption. Uric acid is reabsorbed by a sodium-gradient-independent mechanism (19) and was chosen as a nonspecific control for carnitine reabsorption.

Plasma phosphate concentration and filtered load of phosphate (indexed to GFR) were higher ($P < 0.05$) after the low-protein diet than after the high-protein diet (**Table 7**). The difference in plasma phosphate concentrations after the high- and low-protein diets is not readily explained. The test diets were designed to contain equal amounts of phosphorus (182 mg/kJ). Of the test diets, the high-protein diet contained the largest amount of phosphorus (182 mg/kJ) and the low-protein diet contained the least amount of phosphorus (70 mg/kJ) before supplementation. The low-protein diet was supplemented with phosphorus in the forms of phosphoric acid and dibasic sodium phosphate to match the phosphorus content of the high-protein diet. Although individual diets were not analyzed for phosphorus content, we suspect that similar amounts of phosphorus were consumed. It is possible that the total (endogenous plus supplemented) phosphorus content of the low-protein diet exceeded the endogenous phosphorus content of the high-protein diet, or that the supplemented forms of phosphorus are more readily absorbed than are the endogenous form, resulting in higher plasma phosphate concentrations.

Because the rate of phosphate reabsorption, expressed as mmol/L glomerular filtrate, was similar among the different diets, the difference in filtered load was reflected in phosphate excretion. Despite a lower GFR after the low-protein diet, phosphate excretion was higher after the low-protein diet than after the high-protein ($P < 0.01$) or control ($P < 0.05$) diets. Phosphate excretion was higher after the high-fat diet than after the high-carbohydrate diet ($P < 0.01$), probably because of marginal differences in plasma phosphate concentrations observed with these diet treatments. It is interesting to note, in retrospect, that the two diets that resulted in the highest plasma phosphate concentrations and rates of phosphate excretion (low-protein and high-fat) were also the diets with the highest percentage of phosphorus from the supplement (64% and 27%, respectively).

There were no differences in filtered load or rate of uric acid reabsorption after any of the test diets. Although uric acid excretion, expressed as mmol/L glomerular filtrate, was not different after the low- or high-protein diets, it was lower after the low-protein diet than after the control diet. Uric acid contents of the diet were not determined, nor were they held constant.

Because neither phosphorus nor uric acid demonstrate the same response to macronutrient composition of the diet as does carnitine, we conclude that our observations for carnitine cannot be generalized to all solutes. It is likely that other factors, such

TABLE 7
Plasma concentration, filtered load, reabsorption, and excretion of phosphate on day 6*

Diet	Plasma concentration	Filtered load	Reabsorption	Excretion
	mmol/L	*mmol/L GF*	*mmol/L GF*	*mmol/L GF*
High protein	1.01 ± 0.12[a]	1.00 ± 0.04[a]	0.89 ± 0.12	0.11 ± 0.01[a]
Low protein	1.08 ± 0.10[b]	1.09 ± 0.03[b]	0.93 ± 0.11	0.16 ± 0.03[b]
Control	1.05 ± 0.15[ab]	1.05 ± 0.05[ab]	0.93 ± 0.16	0.12 ± 0.02[a]
High carbohydrate	1.00 ± 0.10[a]	1.00 ± 0.04[a]	0.90 ± 0.10	0.11 ± 0.01[a]
High fat	1.08 ± 0.14[b]	1.08 ± 0.04[b]	0.93 ± 0.12	0.15 ± 0.01[b]

* $\bar{x}$ ± SEM. GF, glomerular filtrate. Within the same column, values with the different superscript letters are significantly different, $P < 0.05$.

as hormonal differences associated with different macronutrient intakes, affect excretion and reabsorption of various solutes differently.

Macronutrient composition of the diet may in part explain the differences in rates of carnitine excretion in vegetarians compared with omnivores. Lombard, et al (4) observed that, although plasma carnitine concentrations were on average slightly lower in vegetarians than in omnivores, at a fixed plasma carnitine concentration the rate of carnitine excretion was lower in vegetarians than in omnivores. Our results suggest, however, that the difference in fat content among vegetarian and mixed diets cannot explain the difference in carnitine excretion at a fixed plasma carnitine concentration because the filtered load of carnitine would remain constant. The low-protein composition of vegetarian diets could account for the decreased carnitine excretion among vegetarians, assuming GFR was simultaneously low. Rebouche et al (20) found the mean GFR of 12 strict vegetarians on self-selected diets to be 102 $mL \cdot min^{-1} \cdot 1.73\ m^{-2}$. This value is consistent with the mean GFR of 104 $mL \cdot min^{-1} \cdot 1.73\ m^{-2}$ determined after our low-protein diet. That vegetarian diets are lower in protein and fat than are mixed, omnivorous diets is well-documented. The macronutrient composition of strict vegetarian diets was reported to be 29% fat, 10% protein, and 61% carbohydrate compared with the corresponding macronutrient distributions of 40%, 12.5%, and 47.5%, respectively, of mixed diets (21). The macronutrient composition of lactoovovegetarian diets tends to be slightly higher in protein (14.6%) and fat (32.8%) and lower in carbohydrate (52.6%) than strict vegetarian diets (22). The difference in macronutrient composition between the strict-vegetarian and lactoovovegetarian diets is attributed primarily to the inclusion of dairy products in the latter diet. Similar results were reported elsewhere (23–26).

We conclude that dietary macronutrient content affects plasma carnitine concentration and urinary carnitine excretion in humans. Increased rate of carnitine excretion after a high-protein diet, compared with a low-protein diet, is due to higher GFR. An increased rate of carnitine excretion after a high-fat diet, compared with a high-carbohydrate diet, is due to a higher filtered load of carnitine. The efficiency of carnitine reabsorption is not altered after any of these dietary treatments.

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References

1. Rebouche CJ, Chenard CA. Metabolic fate of dietary carnitine in human adults: identification and quantification of urinary and fecal metabolites. J Nutr 1991;121:539–46.
2. Engel AG, Rebouche CJ, Wilson DM, Glasgow AM, Romshe CA, Cruse RP. Primary systemic carnitine deficiency. II. Renal handling of carnitine. Neurology 1981;31:819–25.
3. Cederblad G. Effect of diet on plasma carnitine levels and urinary carnitine excretion in humans. Am J Clin Nutr 1987;45:725–9.
4. Lombard KA, Olson AL, Nelson SE, Rebouche CJ. Carnitine status of lactoovovegetarians and strict vegetarian adults and children. Am J Clin Nutr 1989;50:301–6.
5. Watt BK, Merrill AL. Composition of foods: raw, processed, prepared. Agriculture handbook no. 8. Washington, DC: US Government Printing Office, 1963.
6. US Department of Agriculture. Composition of foods. Agriculture handbook no. 8-1 through 8-14. Washington, DC: US Government Printing Office, 1976–1986.
7. Leveille GA, Zabik ME, Morgan KJ. Nutrients in foods. Cambridge, MA: The Nutrition Guild, 1983.
8. Jolliffe N, Alpert E. "The performance index" as a method for estimating effectiveness of reducing regimes. Postgrad Med 1951;9:106–15.
9. Liedtke RR, Duarte CG. Laboratory protocols and methods for the measurement of glomerular filtration rate and renal plasma flow. In: Duarte CG, ed. Renal function tests: clinical laboratory procedures and diagnosis. Boston: Little, Brown, and Co, 1980:49–63.
10. Rebouche CJ, Bosch EP, Chenard CA, Schabold KJ, Nelson SE. Utilization of dietary precursors for carnitine biosynthesis in human adults. J Nutr 1989;119:1907–13.
11. Daly JA, Ertingshausen G. Direct method for determining inorganic phosphorus in serum with the "Centrifichem". Clin Chem 1972;18:263–5.
12. Fossati P, Principe L, Berti G. Use of 3,5-dichloro-2-hydroxybenzene sulfonic acid/4-aminophenazone chromogenic system in direct enzymatic assay of uric acid in serum and urine. Clin Chem 1980;26:227–31.
13. Fomon SJ, Thomas LN, Jensen RL, May CD. Determination of nitrogen balance of infants less than 6 months of age. Pediatrics 1958;22:94–100.
14. Jeejeebhoy KN, Ahmad S, Kozak G. Determination of fecal fats containing both medium and long chain triglycerides and fatty acids. Clin Biochem 1970;3:157–63.
15. Statistical Analysis System Institute. SAS user's guide: statistics. 5th ed. Cary, NC: SAS Institute, Inc, 1985.
16. Bloch AS, Shils ME. Appendix. In: Shils ME, Young VR, eds. Modern nutrition in health and disease. Philadelphia: Lea and Febiger, 1988:1514.
17. Pullman TN, Alving AS, Dern RJ, Landowne M. The influence of dietary protein intake on specific renal functions in normal man. J Lab Clin Med 1954;44:320–32.
18. Chen L, Sacktor B. Sodium gradient dependent phosphate transport in renal brush border membrane vesicles. J Biol Chem 1981; 256:1556–64.
19. Kahn AM, Weinman EJ. Urate transport in the proximal tubule: in vivo and vesicle studies. Am J Physiol 1985;249:F789–98.
20. Rebouche CJ, Lombard KA, Chenard CA. Renal adaptation to dietary carnitine in humans. Am J Clin Nutr (in press).
21. Abdulla M, Andersson I, Asp N, et al. Nutrient intake and health status of vegans. Chemical analyses of diets using the duplicate portion sampling technique. Am J Clin Nutr 1981;34:2464–77.
22. West RO, Hayer OB. Diet and serum cholesterol levels. A comparison between vegetarians and nonvegetarians in a Seventh-day Adventist group. Am J Clin Nutr 1968;21:853–62.
23. Lloyd T, Schaeffer JM, Walker MA, Demers LM. Urinary hormonal concentrations and spinal bone densities of premenopausal vegetarian and nonvegetarian women. Am J Clin Nutr 1991;54:1005–10.
24. Calkins BM, Whittaker DJ, Nair PP, Rider AA, Turjman N. Diet, nutrition intake, and metabolism in populations at high and low risk for colon cancer. Am J Clin Nutr 1984;40:896–905.
25. Thorogood M, Roe L, McPherson K, Mann J. Dietary intake and plasma lipid levels: lessons from a study of the diet of health conscious groups. Br Med J 1990;300:1297–301.
26. Millet P, Guilland VC, Fuchs F, Klepping J. Nutrient intake and vitamin status of healthy French vegetarians and nonvegetarians. Am J Clin Nutr 1989;50:718–27.