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Metabolic balance studies and dietary protein requirements in patients undergoing continuous ambulatory peritoneal dialysis

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Metabolic balance studies and dietary protein requirements in patients undergoing continuous ambulatory peritoneal dialysis. Balance studies for nitrogen, potassium, magnesium, phosphorus, and calcium were carried out in eight men undergoing continuous ambulatory peritoneal dialysis (CAPD) to determine dietary protein requirements and mineral balances. Patients were fed high energy diets for 14 to 33 days which provided either 0.98 (seven studies) or 1.44 g (six studies) of primarily high biological value protein/kg body wt/day. Mean nitrogen balance was neutral with the lower protein diet (+0.35 ± 0.83 SEM g/day) and strongly positive with the higher protein diet (+2.94 ± 0.54 g/day). With the higher protein diet the balances for potassium, magnesium, and phosphorus were strikingly positive, there was an increase in body weight in all patients, and a rise in mid-arm muscle circumference in five of the six patients. The relation between protein intake and nitrogen balance suggests that the daily protein requirement for clinically stable CAPD patients should be at least 1.1 g/kg/day; to account for variability among subjects 1.2 to 1.3 g protein/kg/day is probably preferable. Potassium balance correlated directly with nitrogen balance ($r = 0.81$). High fecal potassium losses (19 ± 1.2 mEq/day) in all patients probably helped maintain normal serum potassium concentrations. Mean serum magnesium was increased (3.1 ± 0.1 mg/dl), and magnesium balances were positive suggesting that the dialysate magnesium of 1.85 mg/dl is excessive. The net gain of calcium from dialysate was 84 ± 18 mg/day; this correlated inversely with serum calcium levels ($r = -0.90$).

Bilans métaboliques et besoins protéiques alimentaires de malades en dialyse péritonéale continue ambulatoire. Des études de bilan de l'azote, du potassium, du magnésium, du phosphore et du calcium, étaient fait en sept hommes en dialyse péritonéale continue ambulatoire (CAPD), pour déterminer leurs besoins protéiques alimentaires et leur bilan minéral. Les malades ont reçu pendant 14 à 33 jours des régimes hautement énergétiques, apportant soit 0,98 (sept études), soit 1,44 g (six études) de protéines de haute valeur biologique par kg de poids et par jour. Le bilan azoté moyen était nul avec le régime comportant la plus faible teneur protéique (+ 0,35 ± 0,88 g/j SEM) et était fortement positive avec le régime à plus forte teneur protéique (+2,94 ± 0,54 g/j). Avec le régime à haute teneur en protéine, les bilans potassique, magnésien et phosphoré étaient fortement positifs; le poids corporel s'est élevé chez tous les malades; la circonférence musculaire mesurée du milieu du bras a augmenté chez cinq sur six malades. La relation existant entre l'apport protéique et le bilan azoté suggère que les besoins journaliers en protéines pour des malades cliniquement stables en CAPD devraient être au moins de 1,1 g/kg/j; 1,2 à 1,3 g de protéines/kg/j sont sans doute préférables pour tenir compte de la variabilité entre les sujets. Le bilan potassique était directement corrélé avec la balance azotée ($r = 0,81$). De fortes pertes potassiques fécales (19 ± 1,2 mEq/j) chez tous les malades ont probablement contribué à maintenir normales les concentrations sériques du potassium. La magnésémie moyenne était élevée (3,1 ± 0,1 mg/dl), et les bilans magnésiens aient positifs suggérant que le magnésium du dialysat (1,85 18 mg/dl) était trop élevé. Le gain net en calcium à partir du dialysat était de 84 ± 18 mg/j; ce gain était inversement corrélé avec la calcémie ($r = 0,90$).

Continuous ambulatory peritoneal dialysis (CAPD) is an increasingly utilized form of maintenance dialysis therapy [1–3]. Although many clinical and metabolic benefits are ascribed to CAPD, very little is known about nitrogen and mineral balances or dietary protein requirements during such treatment. This problem is of particular relevance because wasting and malnutrition occur frequently in patients undergoing other forms of maintenance dialysis therapy [4–6]. It has been suggested that patients undergoing chronic intermittent peritoneal dialysis are likely to develop wasting, in part because of the protein losses during dialysis [7, 8]. The nutritional status of CAPD patients is not well documented. Many patients seem to gain weight [3]. However, a reduction in total body potassium has been reported in some CAPD patients [9].

The present study was designed to evaluate the dietary protein requirements and balances for potassium, magnesium, phosphorus, and calcium in CAPD patients. Studies were performed under the controlled conditions of a metabolic balance unit. Thirteen studies were conducted in eight clinically stable men undergoing CAPD while they ingested two different high energy, isocaloric diets. Protein intakes averaged either 0.98 g/kg body wt/day, an intake commonly recommended for patients undergoing maintenance hemodialysis, or 1.44 g protein/kg body wt/day.

Methods

Thirteen metabolic balance studies were carried out during CAPD in eight men, aged 27 to 59 years, either at the Special Diagnostic and Treatment Unit at the Veterans Administration Wadsworth Medical Center or the Clinical Research Center at the University of California, Los Angeles, Center for the Health Sciences. The clinical and nutritional characteristics of the patients prior to the initial metabolic balance studies and those in 60 normal male hospital employees who served as controls are shown in Table 1. Five patients were anuric, while three had minimal residual renal function. The patients had undergone

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Table 1. Clinical and nutritional characteristics in CAPD patients and in normal male hospital employees

Patient no.	Age *years*	Duration dialysis *months*	GFR[b] *ml/min*	Hematocrit *vol%*	Weight *kg*	Relative body wt[c] *%*	Body fat[c] *%*
CAPD patients[a]							
1	52	5	1.9	24	70.5	98	22.5
2	47	76	0	37[f]	71.2	105	17.0
3	51	17	1.0/0[e]	38[f]	77.5	108	16.0
4	36	113	0	29[f]	77.5	85	16.0
5	27	7	3.0	27	78.5	99	18.0
6	37	84	0	26	82.5	107	19.5
7	41	65	0	34[f]	89.8	124	22.0
8	59	27	0	25	75.6	105	16.5
Mean ± SEM	43.8 ± 3.4	49.3 ± 14		30.0 ± 2.0	77.9 ± 2.2	104 ± 3.9	18.4 ± 0.9
Normal hospital employees[i]							
Mean ± SEM	46.5 ± 1.2	—	ND	ND	79.8 ± 1.5	104 ± 2.0	21.2 ± 0.6

[a] All data were obtained at the beginning of their first metabolic study.
[b] GFR was calculated as the mean of creatinine and urea clearance [13].
[c] Methods for measuring the values are described previously [6].
[d] Includes histidine; tryptophan was not measured by the procedures employed.
[e] Patient became anuric during the 6-month interval between the two studies.
[f] Indicates patients treated with testosterone.
[g] Indicates race of patient was black.
[h] Indicates race of patient was white.
[i] Normals were a group of 60 male hospital employees ingesting 115 g protein/day [6].
[j] Data based on values from nine normal men.
[k] $P < 0.05$ from corresponding value for CAPD patients.
[l] $P < 0.01$ from corresponding value for CAPD patients.
ND represents data not obtained.

various forms of dialysis for an average of 49 months (range, 5 to 113 months) prior to the evaluation. The duration of treatment with CAPD prior to the initial study varied from 0.5 to 5 months. The average hematocrit was 30 vol%; four patients had received anabolic steroids prior to the study and continued the same treatment. The patients' dietary intake prior to each study, calculated from dietary diaries and recall interviews, were estimated to provide 1.1 ± 0.1 SEM g protein/kg body wt/day, and 25.2 ± 2.1 kcal/kg body wt/day. This intake does not include additional energy derived from glucose absorbed from peritoneal dialysate. Informed consent was obtained from each patient.

Methods for estimating relative body weight, skinfold thickness, body fat, and mid-arm muscle circumference have been described previously [6]. In brief, skinfold thickness was measured in three locations with a Lange® skinfold caliper; body fat was calculated from the skinfold values and relative body weight with the aid of a nomogram [10]. Mid-arm muscle circumference, an indicator of muscle mass, is the mid-arm circumference minus subcutaneous fat, measured by triceps skinfold thickness [11]. Total body potassium was measured with a whole body potassium counter [12].

In comparison with "normals" of similar age, the CAPD patients showed no differences in absolute body weight, relative body weight, body fat, or mid-arm circumferences. Based on comparison to another group of 18 normal individuals, divided according to race, two patients had total body potassium that was below normal, and the value was borderline in three. The serum levels of total protein, albumin, and transferrin (Table 1) and C3 (104 ± 5 mg/dl) were each below normal ($P < 0.01$); initial values for serum IgG, IgA, IgM, and C4 were normal. Plasma concentrations of total essential amino acids were slightly lower from those in nine normal males ingesting "normal" protein diets, $P < 0.05$ (Table 1). Amino acid concentrations at the onset of the two dietary protein studies did not differ.

Patients were given a constant diet calculated to provide either 1.0 or 1.4 g protein/kg body wt/day as shown in Table 2. Actual protein intake averaged 76 ± 2.1 and 114 ± 1.7 g/day. The quantity of high biological value protein with each of these diets was 51 ± 2.6 and 94 ± 2.0 g/day. Five patients were studied with both diets; three ingested the higher protein diet first, the other two ingested the alternate sequence. Patients ingested each diet for two to five days before data collection

Table 1. (Continued)

Mid-arm muscle circumference[c] *cm*	Total body potassium *g/kg*	Serum proteins: Protein *g/dl*	Albumin *g/dl*	Transferrin *mg/dl*	Plasma amino acids: Essential[d] *µmoles/liter*	Nonessential *µmoles/liter*
CAPD patients[a]						
26.1	ND[h]	5.6	3.3	136	843	1982
26.4	2.14[h]	5.9	3.3	167	520	1492
31.1	2.48[g]	6.3	3.7	262	946	2932
22.9	1.37[g]	5.8	2.8	174	802	2445
24.8	1.80[g]	5.9	3.3	226	1361	2029
30.1	1.78[h]	6.0	3.8	186	685	1614
29.5	1.41[h]	7.2	3.5	283	637	1720
31.1	1.75[g]	6.1	2.9	188	700	1553
27.8 ± 1.1	1.85 ± 0.23[g] 1.78 ± 0.21[h]	6.10 ± 0.20	3.32 ± 0.12	203 ± 18	812 ± 91	1971 ± 177
Normal hospital employees[i]						
27.1 ± 0.4	2.05 ± 0.06[g] 1.88 ± 0.04[h]	7.38 ± 0.08[l]	4.98 ± 0.05[l]	303 ± 5[l]	1030 ± 40[j, k]	2001 ± 135[j]

began. The diets provided 2565 ± 68 kcal/day. Fat, carbohydrate, and protein provided 47 ± 2.1%, 39 ± 2.2% and 14 ± 0.9%, respectively, of the dietary energy intake. The total energy intake including glucose absorbed from the peritoneal dialysate was 3249 ± 82 kcal/day (41.7 ± 1.1 kcal/kg) and did not differ with the two levels of protein intake. The intake of deionized water and sodium chloride was varied to maintain fluid and salt balance. All patients received a daily vitamin supplement which contained the B vitamins, folic acid, and ascorbic acid. An average of 7.8 ± 1.0 g/day (range, 3.4 to 15.7) of aluminum hydroxide gel was consumed.

Metabolic balance studies were carried out as described elsewhere [14–16]. All urine and dialysate outflow collected over 24-hr periods were refrigerated immediately. Brilliant blue was given to identify the beginning and end of each 7-day fecal collection period. Duplicate diets (prepared weekly), rejected food, emesis, urine collections, dialysate pools, and feces were each analyzed for nitrogen, potassium, magnesium, phosphorus, and calcium. On alternate days, about 35 ml of blood was obtained by venipuncture before breakfast and after a fast from the previous evening. Studies were carried out with each diet for 14 to 33 days (mean, 20).

Daily balances were calculated as the difference between intake and the sum of fecal, urinary, and dialysate output. Nitrogen balance was adjusted for changes in body urea nitrogen but not for unmeasured losses from skin, respiration, flatus, and blood sampling. Urea nitrogen appearance, a measure of net urea production, was calculated according to the following equation (all in g/day):

$$\text{Urea nitrogen appearance} = \text{urine urea nitrogen} + \text{dialysate urea nitrogen} + \text{change in body urea nitrogen.}$$

The changes in body urea nitrogen were calculated as previously described [17].

CAPD was performed utilizing commercially available 2-liter bags of dialysate. The dialysate composition, as reported by the manufacturer (Baxter-Travenol Laboratories, Deerfield, Illinois), was sodium 132, chloride 102, lactate 35, calcium 3.5, and magnesium 1.5 (all in mEq/liter), and dextrose either 1.5 or 4.25 g/dl. CAPD was performed as described by Oreopoulos et al [18]. Patients exchanged three to five 2-liter bags during each 24-hr period. The volumes of inflow and outflow dialysate were calculated from the weight and specific gravity of the dialysate. The measured dialysate volume instilled averaged 2.06 ± 0.01 liter/bag, and the average daily outflow volume was 10.8 ± 0.49 liter/day (range, 7.7 to 12.9 liter/day). Dialysis clearance was calculated as follows:

$$\text{Dialysis clearance (liter/day)} = \frac{\text{Dialysate concentration (g/liter)} \times \text{Volume of dialysate outflow (liter/day)}}{\text{Plasma concentration (g/liter)}}.$$

Total clearances for urea and creatinine, the sum of dialysis and endogenous renal clearances, were 10.7 ± 0.29 liter/day and 9.4 ± 0.52 liter/day, respectively; they did not differ with the two levels of protein intake (Table 2).

Nitrogen was measured by a modification of the macro-Kjeldahl technique, potassium by flame photometry, and calcium and magnesium by atomic absorption spectrometry. Urea, creatinine, and phosphorus were measured with a Technicon Auto Analyzer®. For measurement of amino acids, 1 ml of plasma was deproteinized with 45 mg of sulfosalicylic acid. Dialysate, collected over one 24-hr period in 12 of the 13

Table 2. Dietary intakes and characteristics of dialysis patients undergoing CAPD while receiving different protein intakes

1.0 g/kg body wt

Patient	Duration of study *days*	Protein intake		Dietary energy intake *kcal/day*	Total energy intake[a]		C_{UREA}			C_{CREAT} Total
		g/day	*g/kg/day*		*kcal/day*	*kcal/kg/day*	Dialysate	Renal	Total *liter/day*	
1	14[b]	62	0.88	2604	3159[c]	44.9[c]	10.3	1.5	11.8	11.6
2	21	68	0.95	2502	2847	40.0	12.1	0	12.1	7.1
3	21[b]	85	1.09	2413	3341	43.1	10.3	0.9	11.2	11.8
4	21[b]	84	1.08	2682	3692	47.6	9.1	0	9.1	8.7
5	14	79	1.00	2846	3405	43.4	8.0	1.8	9.8	11.3
6										
7	14	79	0.88	2209	2943	32.8	11.7	0	11.7	9.3
8	21[b]	72	0.95	2075	2834	37.5	9.0	0	9.0	7.1
Mean ± SEM	18 ± 1.4	76 ± 3.2[e]	0.98 ± 0.03[e]	2476 ± 101	3174 ± 122	41.3 ± 1.9	10.07 ± 0.56	—	10.67 ± 0.50	9.56 ± 0.77

[a] Total energy intake is the sum of energy from the diet and from glucose absorbed from dialysate. Glucose absorption was measured according to methods previously described [23].

[b] Indicates initial study. Patients two and three were restudied 5 months later; studies on patients four, five, and seven were done consecutively.

[c] Glucose absorption from dialysate not measured in this patient but was calculated from the equation; glucose absorption (g/liter of dialysate inflow) = 11.3 (mean dialysate glucose) − 11 [23].

[d] Four 2-liter bags/day exchanged for the initial 14 days and five 2-liter bags/day for the final 7 days of study.

[e] $P < 0.001$, by paired t test from corresponding value obtained with 1.4 g/kg protein diet.

Values represent mean SEM of data obtained during entire 14 to 33 days of study.

SEM of seven values on the 1.0 and six values on the 1.4 g/kg protein diets.

studies, and the supernatant from plasma were analyzed with a Beckman 121 M Amino Acid Analyzer (Beckman Instruments Corp., Fullerton, California) using a lithium buffer system. Serum and dialysate total protein was measured by the biuret method [19]; serum albumin was measured by the brom-cresol green technique [20]; transferrin, C_3, C_4, IgG, IgA, and IgM were measured with radial immuno-diffusion plates [21]. Prior to analysis for protein, the dialysate samples were concentrated 200-fold with an Amicon ultrafiltration cell utilizing a PM-10 membrane with a cut off of 10,000 daltons. Recovery studies in dialysate yielded 101.6 ± 0.4% for nitrogen and 97.5 ± 2.5% for potassium. Protein intake was calculated by multiplying the measured dietary nitrogen by 6.25. Dietary energy intake was calculated from standard food tables [22].

Data on glucose absorption, dialysate protein, amino acid losses and the fractionation of nitrogen excretion during some of the metabolic studies have been reported previously [23–26].

Results were analyzed using a BMD computer program [27]. Statistical analysis was performed with the paired t test, linear regression analysis, and nonlinear regression. Values are expressed as mean ± 1 SEM, unless otherwise noted.

Results

Serum chemistries during the study with the two levels of dietary protein are summarized in Table 3. Serum urea nitrogen (SUN) averaged 67 ± 5.5 mg/dl with the 1.0 g/kg body wt protein diet and 91 ± 7.0 mg/dl with the 1.4 g/kg body wt protein diet ($P < 0.02$). Serum creatinine, potassium, calcium, phosphorus, magnesium, and bicarbonate did not differ with the two diets. Although there was some variation in the serum values during the first week with each diet, these data were generally quite constant thereafter; for example, after the first week of study with each diet, the mean coefficient of variation for SUN in all patients was 5.6% (range, 1.4 to 11.8%).

The nitrogen balance data are shown in Table 4 and Figure 1. With the higher protein diet, fecal nitrogen, total nitrogen output, and urea nitrogen appearance were each significantly greater than with the lower protein diet. In the four studies in patients who were excreting urine, the urinary nitrogen varied from 1.0 to 2.6 g/day or 8.9 to 20.0% of total nitrogen output. Dialysate was the principle source of nitrogen loss, accounting for 88% of total nitrogen output in the patients with no urine output. Urea was the major nitrogenous component in dialysate and comprised 67 ± 2.9% and 74.4 ± 2.4% of total dialysate nitrogen with the lower and higher protein diets, respectively. Losses of total protein and amino acids into dialysate did not differ with the two diets; the mean values for these constituents in dialysate were 9.2 ± 0.6 and 3.3 ± 0.4 g/24 hr, respectively. Thus, total nitrogen from protein and amino acids accounted for 21 ± 3.9% of total dialysate nitrogen with the lower protein diet and 17 ± 1.6% of dialysate nitrogen with the higher protein diet.

Overall nitrogen balance, adjusted for changes in body urea nitrogen but not for unmeasured losses, was +0.35 ± 0.83 g/day with the 1.0 g/kg protein diet and +2.94 ± 0.54 g/day with the 1.4 g/kg diet; only the latter value was significantly greater than zero ($P < 0.001$) (Table 4). Nitrogen balance was somewhat

Table 2. (Continued)

1.4 g/kg body wt

Duration of study	Protein intake		Dietary energy intake	Total energy intake[a]		C_{UREA}			C_{CREAT} Total
days	*g/day*	*g/kg/day*	*kcal/day*	*kcal/day*	*kcal/kg/day*	Dialysate	Renal	Total	
						liter/day			
21[b]	108	1.44	2483	2870	40.3	11.8	0	11.8	8.4
21	116	1.52	2773	3330	43.0	10.2	0	10.2	8.7
33	117	1.44	2430	3596	46.4	10.6	0	10.6	9.6
21[b]	111	1.43	2865	3461	44.1	7.7	3.3	11.0	12.1
21[b]	116	1.41	2650	3252	39.4	9.7/10.4[d]	0	9.7/10.4	6.5/7.1
21[b]	119	1.37	2817	3509	39.1	11.4	0	11.4	9.3
23 ± 2.0	114 ± 1.7	1.44 ± 0.02	2670 ± 74	3336 ± 106	42.1 ± 1.2	10.27 ± 0.59	—	10.82 ± 0.29	9.13 ± 0.72

more positive with the higher protein diet than with the lower protein diet, but this did not reach significance; paired *t* test ($P = 0.06$). For the individual patients studied on both diets, the balances were significantly greater with the higher protein diet ($P < 0.01$) for four of the five patients; for the fifth patient (case 3 in Table 4), the balances did not differ.

The relationship between nitrogen and protein intake is shown in Figure 2. When the studies with the high and low protein diets were analyzed together, the relationship between nitrogen balance and protein intake was curvilinear; there was no further increment in nitrogen balance above a protein intake of 1.09 g/kg/day. Dietary potassium, magnesium, phosphorus, and calcium each varied directly with nitrogen intake (Tables 4 to 8 and Fig. 1).

The results for potassium balance are shown in Table 5 and Fig. 1. Dietary potassium intake averaged 64 mEq/day with the lower protein diet and 84 mEq/day with the higher protein intake. Serum potassium averaged 4.3 ± 0.2 mEq/liter with both diets combined, and dialysate potassium losses correlated with the serum levels ($r = 0.74$, $P < 0.01$). A striking feature was the loss of 17 to 31% of dietary potassium in the stool, with a loss of 16.9 ± 1.1 mEq/day with the low protein diet and 20.4 ± 2.1 mEq/day with the high protein diet. Fecal potassium losses correlated with dietary potassium intake ($r = 0.61$; $P < 0.05$) but not with serum potassium levels. Net potassium absorption (dietary intake minus fecal losses) correlated with potassium intake; $r = 0.97$, $P < 0.001$. Potassium balance was neutral with the 1.0 g/kg diet (+6.8 ± 4.6 mEq/day) and significantly greater than zero with the 1.4 g/kg diet; +17.8 ± 4.0 mEq/day, $P < 0.01$. Potassium balance correlated directly with the dietary intake of potassium: Potassium balance (mEq/day) equals 0.64 diet intake (mEq/day) minus 35; $r = 0.80$, $P < 0.01$; potassium balance also correlated with nitrogen balance; $r = 0.81$, $P < 0.001$.

The results for magnesium balance during 12 studies are shown in Table 6 and Figure 1. The concentration of magnesium measured in several different lots of dialysate was 1.85 ± 0.003 mg/dl, and serum magnesium levels were 3.1 ± 0.1 mg/dl with both diets (normal range for serum magnesium, 1.6 to 2.7 mg/dl). There was a net loss of magnesium into dialysate in all studies but one. The quantity of magnesium removed in the dialysate averaged 46 ± 7.5 mg/day and correlated with the serum magnesium concentrations; $r = 0.88$, $P < 0.01$. In all but one study, the patients exhibited neutral or positive magnesium balances, and the mean magnesium balance was slightly greater when patients ingested the high protein diets than with the lower protein diets; $P < 0.05$. Magnesium balance correlated inversely with fecal loss; $r = 0.70$, $P < 0.02$. Net magnesium absorption (dietary intake minus fecal losses) ranged from 74 to 200 mg during 11 studies, a single patient (case 6) exhibited high fecal losses of magnesium and calcium and negative net absorption of these minerals (Tables 7 and 8 and Fig. 1). The relationship between dietary magnesium intake and net magnesium absorption is shown in Figure 3; these data are shown in relation to previously published data in patients with chronic uremia [16, 28, 29].

The data for phosphorus balance are shown in Table 7 and Figure 1. Dietary phosphorus intake was substantially greater with the high protein diet due to the greater intake of dairy products. There was a positive correlation between the balance for phosphorus and that for potassium; $r = 0.64$, $P < 0.05$. In the patients eating both diets, the increment in phosphorus balance correlated with the change in phosphorus intake: $r = 0.93$, $P < 0.05$. Despite the ingestion of 7.8 ± 1.0 g/day of aluminum hydroxide, net phosphorus absorption was related to phosphorus intake: $r = 0.87$, $P < 0.001$. The relationship between net absorption of phosphorus and dietary phosphorus intake is shown in Figure 4. The observations for the patients treated with CAPD fell along the same regression slope seen in patients with chronic uremia [16, 30, 31].

The results for calcium balance are shown in Table 8 and Figure 1. The concentration of calcium in dialysate was 6.9 ± 0.03 mg/dl. Total serum calcium averaged 9.0 ± 0.3 mg/dl during all 13 studies. Net calcium uptake from dialysate aver-

Table 3. Serum chemistries in patients undergoing CAPD while receiving different protein intakes

	1.0 g/kg body wt						
	Urea Nitrogen	Creatinine	Potassium	Calcium	Phosphorus	Magnesium	Bicarbonate
Patient no.	*mg/dl*		*mEq/liter*	*mg/dl*			*mEq/liter*
1	65 ± 4.0	10.0 ± 0.15	3.6 ± 0.26	10.2 ± 0.22	4.4 ± 0.31	ND	27.8 ± 0.63
2	74 ± 3.8	19.2 ± 0.31	3.8 ± 0.15	9.0 ± 0.06	5.0 ± 0.11	3.4 ± 0.07	17.8 ± 0.55
3	40 ± 1.3	14.2 ± 0.17	4.0 ± 0.05	7.9 ± 0.19	3.3 ± 0.15	3.1 ± 0.15	29.3 ± 0.63
4	62 ± 1.0	13.3 ± 0.14	3.9 ± 0.06	8.6 ± 0.14	5.1 ± 0.09	3.0 ± 0.07	23.7 ± 0.64
5	71 ± 2.2	14.8 ± 0.32	4.2 ± 0.17	10.8 ± 0.13	5.0 ± 0.28	3.0 ± 0.07	28.2 ± 1.08
6							
7	88 ± 2.1	15.9 ± 0.13	5.1 ± 0.11	7.4 ± 0.09	5.1 ± 0.14	3.2 ± 0.15	18.4 ± 0.61
8	72 ± 1.0	18.5 ± 0.18	3.7 ± 0.07	8.3 ± 0.06	3.8 ± 0.10	2.7 ± 0.10	23.7 ± 0.46
Mean ± SEM[b]	67 ± 5.5	15.1 ± 1.2	4.0 ± 0.19	8.9 ± 0.46	4.5 ± 0.27	3.1 ± 0.10	24.1 ± 1.76

Values represent mean ± SEM of data obtained during entire 14 to 33 days of study. ND = Data not obtained.

[a] Only a single measurement was obtained after 2 weeks of study.

[b] SEM of seven values on the 1.0 and six values on the 1.4 g/kg protein diets.

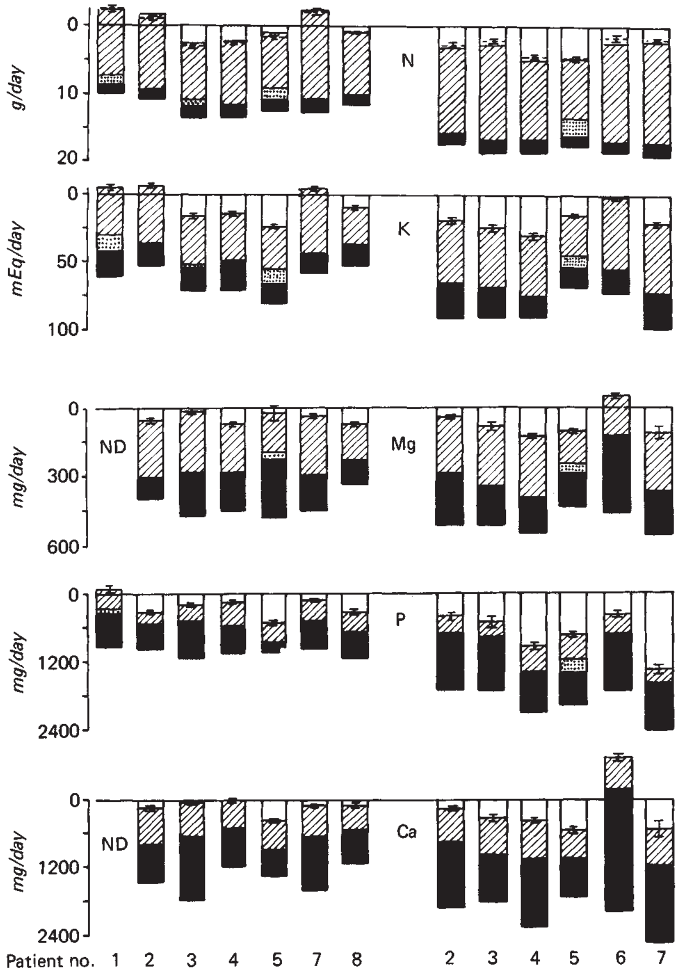

Fig. 1. *Nitrogen, potassium, magnesium, phosphorus, and calcium balances for 13 studies in eight men undergoing CAPD.* The seven balances represented on the left of the figure illustrate data obtained during ingestion of the 1.0 g protein/kg/day diet; the six balances on the right of the figure are from data obtained with the 1.4 g protein/kg/day diet. Data from each study are shown vertically above the *patient number*. Values represent the mean of data obtained during the entire 14 to 33 days of study. Intake is plotted down from the *zero line;* outputs are plotted up from the *line* indicating the intake [14]. The *black area* represents fecal losses, the *dotted area*, urinary output, and the *crosshatched area*, dialysate losses. Nitrogen and mineral balances are represented as mean ± 1 SEM [1]. For the nitrogen balance, the *interrupted lines* indicate the balance adjusted for estimated changes in body urea pool [17]. ND represents data not obtained.

aged 84 ± 18 mg/day and correlated inversely with serum calcium: Net uptake equals 600 minus 58 (serum calcium, mg/dl); $r = -0.90$, $P < 0.001$. Dietary calcium intake was significantly greater with the higher than the lower protein diet. During nine of the 12 studies there was a positive calcium balance (>85 mg/day); the mean calcium balance was slightly greater with the high than the low protein diet, $P < 0.05$. When patient six is excluded, both overall calcium balance and net calcium absorption correlated with dietary calcium intake; $r = 0.74$, $P < 0.01$ and $r = 0.64$, $P < 0.05$, respectively. The relationship between net calcium absorption and dietary calcium intake is shown in Figure 5; these data are superimposed on observations previously reported in patients with chronic uremia [16, 28, 30, 31]. There is a direct correlation between serum calcium levels and net calcium absorption when the data from patient six is excluded: $r = 0.73$, $P < 0.01$. Overall calcium balance correlated with magnesium balance, $r = 0.84$, $P < 0.001$; the change in calcium balance as patients who received

Table 3. (Continued)

1.4 g/kg body wt						
Urea Nitrogen	Creatinine	Potassium	Calcium	Phosphorus	Magnesium	Bicarbonate
mg/dl		*mEq/liter*	*mg/dl*			*mEq/liter*
77 ± 1.3	14.8 ± 0.23	4.0 ± 0.10	8.7 ± 0.12	4.7 ± 0.03	3.1[a]	23.8 ± 0.40
100 ± 3.4	21.7 ± 0.47	4.6 ± 0.13	8.9 ± 0.09	3.5 ± 0.27	3.5 ± 0.05	23.1 ± 0.76
76 ± 1.5	12.9 ± 0.09	4.0 ± 0.12	9.1 ± 0.09	4.6 ± 0.16	3.3 ± 0.07	24.7 ± 0.58
78 ± 1.2	13.7 ± 0.11	3.8 ± 0.12	10.2 ± 0.14	6.4 ± 0.11	2.6 ± 0.05	23.3 ± 0.68
118 ± 4.2	19.3 ± 0.45	5.3 ± 0.10	9.7 ± 0.15	5.6 ± 0.10	2.7 ± 0.05	21.8 ± 0.59
99 ± 2.2	15.8 ± 0.10	5.6 ± 0.13	8.5 ± 0.25	4.0 ± 0.35	3.3 ± 0.13	20.8 ± 0.42
91 ± 7.0	16.4 ± 1.40	4.6 ± 0.31	9.2 ± 0.26	4.8 ± 0.43	3.1 ± 0.15	22.9 ± 0.57

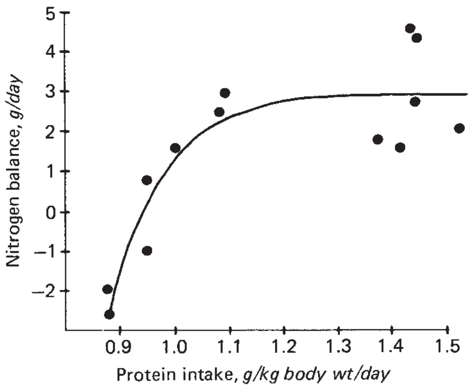

Fig. 2. *Relationship between the dietary protein intake and the nitrogen balance during 13 studies in eight men undergoing CAPD.* Each *circle* represents the mean of data obtained during the 14 to 33 days of study. The calculated relationship between protein intake and nitrogen balance, indicated by the *curved line*, is as follows: Nitrogen balance = $-27935e^{-9.72(\text{protein intake})} + 3.05$.

both diets went from one diet to another correlated with the change in phosphorus balance; $r = 0.88$, $P < 0.05$.

Assessment of various nutritional parameters was performed before and after each study. There was no change in anthropometric measurements during ingestion of the low protein diet. During ingestion of the high protein diet there was a significant increase in body weight, $P < 0.02$ (Fig. 6). Also mid-arm muscle circumference increased in five of the six patients, and the sum of the triceps and subscapular skinfold thickness, an indicator of body fat, rose in four of these patients; these changes were not significant when the six patients were analyzed together. There were no changes in the serum levels of any protein during these short periods of treatment with either diet. The plasma amino acid concentrations did not change; moreover, there were no differences in plasma amino acid levels between the two diets.

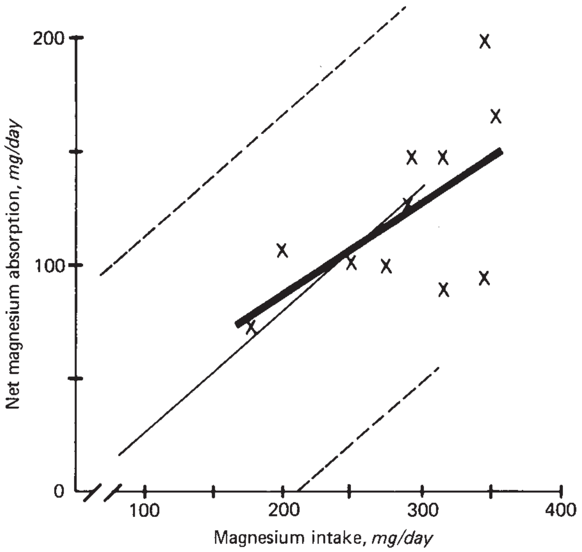

Fig. 3. *Relationship between dietary magnesium intake and net magnesium absorption.* Data for 11 studies in patients undergoing CAPD are indicated by the *crossed lines* (X). Values represent the mean data obtained from the 14 to 33 days of study. The *heavy solid line* depicts the regression analysis, $y = 0.40\text{ X} + 8.1$, $r = 0.61$, $P < 0.05$. Data are not available for patient 1; the data from patient 6 who had abnormally high fecal magnesium losses are omitted from these calculations. For comparison, magnesium absorption data from 24 studies in 16 nondialyzed chronic uremic patients are shown [16, 28]; the *thin solid line* indicates the regression analysis for these data and the *interrupted lines* represent the 95% confidence limits.

Discussion

The present results indicate that in men undergoing CAPD, nitrogen balance is near neutral (+0.35 ± 0.83 g/day) when they ingest approximately 1.0 g protein/kg body wt/day and is significantly positive (+2.94 ± 0.54 g/day) with an intake of 1.4 g/kg/day. When balances are adjusted by about 0.4 g nitrogen/

Table 4. Nitrogen intake, output, and adjusted balance and urea nitrogen appearance all in gN/day in patients undergoing CAPD while receiving different protein intakes

	Diet, 1.0 g/kg body wt						
Patient no.	Diet	Dialysate	Urine	Stool	Total nitrogen output	Urea nitrogen appearance	Adjusted[d] balance
1	9.90	9.64 ± 0.41	1.37	1.34	12.35 ± 0.43	7.52 ± 0.64	−2.55 ± 0.66
2	10.84	11.02 ± 0.35	—	1.50	12.48 ± 0.29	7.93 ± 0.48	−0.97 ± 0.34
3	13.53	8.29 ± 0.10	0.97	1.61	10.87 ± 0.18	4.63 ± 0.14	+3.02 ± 0.28
4	13.45	9.24 ± 0.15	—	1.88	11.12 ± 0.13	5.62 ± 0.32	+2.51 ± 0.24
5	12.50	8.12 ± 0.31	1.72	1.68	11.51 ± 0.31	5.95 ± 0.39	+1.60 ± 0.27
6							
7	12.66	13.06 ± 0.31	—	1.90	14.95 ± 0.27	8.94 ± 0.46	−1.96 ± 0.31
8	11.54	9.25 ± 0.07	—	1.34	10.66 ± 0.07	6.12 ± 0.18	+0.80 ± 0.13
Mean ± SEM[e]	12.06 ± 0.51[c]	9.80 ± 0.65	—	1.61 ± 0.09[a]	11.99 ± 0.56[b]	6.67 ± 0.57[b]	+0.35 ± 0.83

Values represent mean or mean ± SEM of data obtained during entire 14 to 33 days of study. N represents nitrogen.

[a] $P < 0.05$, by paired t test from corresponding values obtained with 1.4 g/kg protein diet.

[b] $P < 0.02$, by paired t test from corresponding values obtained with 1.4 g/kg protein diet.

[c] $P < 0.001$, by paired t test from corresponding values obtained with 1.4 g/kg protein diet.

[d] Nitrogen balance adjusted for change in body urea nitrogen pool but not for blood drawing or insensible losses.

[e] SEM of seven values on the 1.0 and six values on the 1.4 g/kg protein diets.

[f] N balance is significantly greater with the higher than lower protein diet ($P < 0.01$).

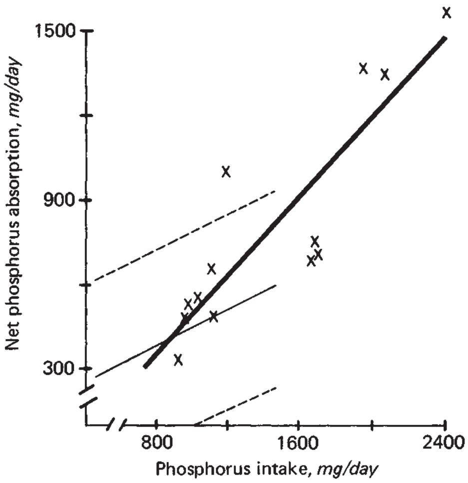

Fig. 4. *Relationship between dietary phosphorus intake and net phosphorus absorption.* Data for 13 studies in patients undergoing CAPD are indicated by the *crossed lines* (X). The *heavy solid line* depicts the regression analysis, $y = 0.70$ X $+207$, $r = 0.87$, $P < 0.001$. For comparison, phosphorus absorption data from 33 studies in 19 nondialyzed chronic uremic patients are shown [16, 30, 31]. The *thin solid line* represents the regression analysis for these data, and the *interrupted lines* represent the 95% confidence limits.

day for unmeasured losses from skin, respiration, and flatus [32], and by an additional 0.4 g nitrogen/day for blood sampling, balances would be somewhat more negative. Even with adjustment for these unmeasured nitrogen losses, nitrogen balance was still strongly positive with the 1.4 g/kg protein diet. Other data which support an anabolic effect of the higher protein diet are the direct correlation between nitrogen balance and potassium balance and the significantly positive phosphorus and magnesium balances with the higher protein diet. Moreover, with the higher protein diet, body weight rose significantly, and mid-arm muscle circumference increased in five of the six patients. The observation that serum proteins did not increase during the study may reflect the relatively short duration of the study, the losses of proteins into dialysate, and/or metabolic derangements in protein metabolism caused by uremia, itself.

In earlier studies, nitrogen balances were reported to be strongly positive in patients undergoing maintenance hemodialysis and receiving high calorie diets which provided 1.25 to 1.62 g of primarily high quality protein/kg body wt/day [33–36]. More recently, Borah et al reported substantially less positive nitrogen balances in four patients who received diets providing 1.38 g protein/kg body wt/day (range 1.21 to 1.47) and underwent hemodialysis three times weekly using modern dialysis techniques [37]. The average nitrogen balance in their patients was +0.03 to +2.57 g/day (grand mean, +1.06 ± 0.59 g/day). If adjustment is made for unmeasured nitrogen losses from skin, respiration, flatus, and blood drawing, two of the four patients would be in negative balance.

Several factors may account for the positive nitrogen balances in our CAPD patients who received the 1.44 g/kg protein diet. First, the total energy intake from food and glucose absorbed from dialysate was high, averaging 42 ± 1.2 kcal/kg body wt/day (Table 2): This compares with an energy intake of 27 ± 1.5 kcal/kg/day in the hemodialysis patients of Borah et al. The CAPD patients were sedentary during the metabolic studies, a factor which might have reduced their energy expendi-

Table 4. (Continued)

Diet, 1.4 g/kg body wt						
Diet	**Dialysate**	**Urine**	**Stool**	**Total nitrogen output**	**Urea nitrogen appearance**	**Adjusted balance**
17.29	12.42 ± 0.12	—	1.70	14.12 ± 0.12	9.6 ± 0.26	+2.84 ± 0.30[f]
18.58	13.92 ± 0.31	—	1.87	15.80 ± 0.34	10.9 ± 0.29	+2.16 ± 0.39
18.65	11.60 ± 0.14	—	2.06	13.66 ± 0.17	8.52 ± 0.29	+4.44 ± 0.20[f]
17.79	8.77 ± 0.20	2.61	1.67	13.02 ± 0.26	8.90 ± 0.44	+4.66 ± 0.37[f]
18.50	14.48 ± 0.24	—	1.54	16.02 ± 0.22	13.09 ± 0.86	+1.66 ± 0.47
19.09	14.80 ± 0.23	—	1.98	16.79 ± 0.26	11.46 ± 0.20	+1.86 ± 0.19[f]
18.32 ± 0.27	12.67 ± 0.93	—	1.80 ± 0.08	14.90 ± 0.61	10.42 ± 0.71	+2.94 ± 0.54

Table 5. Potassium intake, output and balance in patients undergoing CAPD while receiving different protein intakes

	1.0 g/kg body wt					1.4 g/kg body wt				
Patient no.	**Diet**	**Dialysate**	**Urine**	**Feces**	**Balance**	**Diet**	**Dialysate**	**Urine**	**Feces**	**Balance**
					mEq/day					
1	60.7	35.3 ± 0.6	11.6	18.8	−5.0 ± 2.4					
2	52.8	42.9 ± 0.8	—	16.3	−6.4 ± 0.8	90.5	46.7 ± 0.5	—	25.8	+18.1 ± 2.2
3	71.6	35.9 ± 0.8	2.7	17.2	+15.7 ± 1.7	89.8	43.5 ± 0.7	—	22.4	+23.9 ± 3.5
4	71.1	34.2 ± 0.4	—	22.1	+14.7 ± 0.5	89.4	44.2 ± 1.0	—	16.0	+29.2 ± 2.4
5	81.3	32.7 ± 1.2	11.2	13.5	+23.9 ± 1.4	66.8	28.7 ± 0.8	8.7	14.9	+14.5 ± 0.9
6						71.0	53.0 ± 0.8	—	17.2	+0.8 ± 1.1
7	57.8	48.1 ± 0.8	—	14.6	−4.9 ± 1.3	97.0	50.7 ± 0.6	—	26.2	+20.0 ± 1.1
8	52.4	26.8 ± 0.9	—	16.0	+9.6 ± 1.3					
Mean ± SEM[a]	64.0 ± 4.1[b]	36.6 ± 2.6	—	16.9 ± 1.1	+6.8 ± 4.6	84.1 ± 5.0	44.5 ± 3.5	—	20.4 ± 2.1	+17.8 ± 4.0

Values represent mean or mean ± SEM of data obtained during the entire 14 to 33 days of study.

[a] These figures are the SEM of seven values on the 1.0 and six values on the 1.4 g/kg protein diets.

[b] $P < 0.01$, by nonpaired t test from corresponding value obtained with 1.4 g/kg diet.

ture, but the same factor was probably operative for the hemodialysis patients undergoing balance studies. Second, the glucose absorbed from peritoneal dialysate may have had an anabolic effect by stimulating insulin secretion and lowering serum glucagon [38]. This effect on insulin secretion may have been continuous because dialysate glucose is greater than plasma glucose throughout the dialysis cycle. Nitrogen balance was substantially more negative on the days that the patients of Borah et al underwent hemodialysis; it is possible that various factors related to hemodialysis, per se, may have promoted negative balance [39, 40]. It is also possible that the greater removal of toxic "middle molecules" may also contribute to the anabolic effect of CAPD [1].

At the onset of these studies, the anthropometric values in the CAPD patients were not different from normal (Table 1) although the serum total protein, albumin and transferrin concentrations were slightly below normal. However, the serum proteins were no different from those in typical patients undergoing hemodialysis [5, 6]. Because these patients were not severely wasted, it is unlikely that the improvement in nutritional status with the 1.4 g/kg protein diet was due to the exaggerated nutritional improvement which may occur when malnourished patients are fed a nutritious diet [41].

The results of the present study provide data concerning the dietary protein requirements during CAPD. Inspection of Figure 2 indicates that with a dietary protein intake above 1.09

Table 6. Magnesium intake, output and balance in patients undergoing CAPD while receiving different protein intakes

	1.0 g/kg body wt					1.4 g/kg body wt				
Patient no.	Diet	Net[a] dialysate loss	Urine	Feces	Balance	Diet	Net[a] dialysate loss	Urine	Feces	Balance
					mg/day					
2	203	54 ± 2	—	96	+53 ± 8	318	51 ± 3	—	228	+38 ± 7
3	277	74 ± 5	12	177	+14 ± 7	317	67 ± 2	—	170	+80 ± 16
4	293	54 ± 2	—	167	+72 ± 4	347	73 ± 3	—	147	+127 ± 5
5	347	38 ± 4	31	252	+26 ± 35	295	6 ± 1	40	147	+102 ± 10
6						288	9 ± 3	—	337	−58 ± 10
7	253	63 ± 5	—	152	+38 ± 6	355	58 ± 3	—	189	+108 ± 18
8	179	2 ± 6	—	105	+75 ± 7					
Mean ± SEM[b]	259 ± 25[c]	48 ± 10	—	158 ± 23	+46 ± 10[c]	320 ± 11	44 ± 12	—	203 ± 30	+66 ± 28

Values represent mean or mean ± SEM of data obtained during the entire 14 to 33 days of study. Magnesium and calcium balance studies were not performed in patient 1.

[a] Net dialysate loss represents the total inflow magnesium less total effluent magnesium.

[b] These figures are the SEM of six values on the 1.0 and six values on the 1.4 g/kg protein diet.

[c] $P < 0.05$, by paired t test from corresponding values obtained with 1.4 g/kg protein diet.

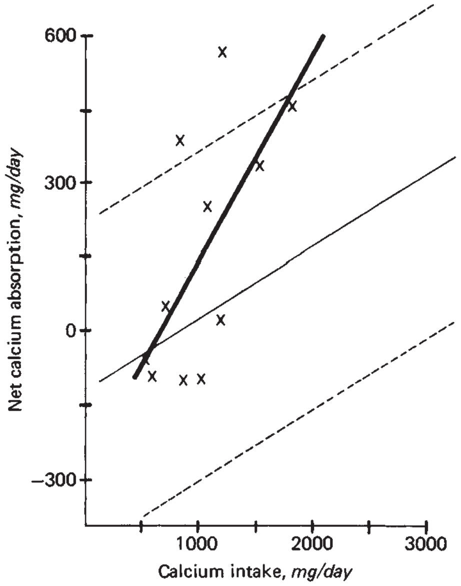

Fig. 5. *Relationship between dietary calcium intake and net calcium absorption.* Data for 11 studies in patients undergoing CAPD are indicated by the *crossed lines* (X). The *heavy solid line* indicates the regression analysis, $y = 0.42 \times -277$, $r = 0.64$, $P < 0.05$. Data are not available for patient 1; data from patient 6 with abnormally high fecal losses are omitted from calculations, as are the data obtained during the last 12 days of study in patient 4 when he was treated with 1,25 dihydroxycholecalciferol. For comparison, calcium absorption data from 41 studies in 27 nondialyzed chronic uremic patients are shown [16, 28, 30, 31]. The *thin solid line* indicates the regression analysis for these data and the *interrupted lines* represent the 95% confidence limits.

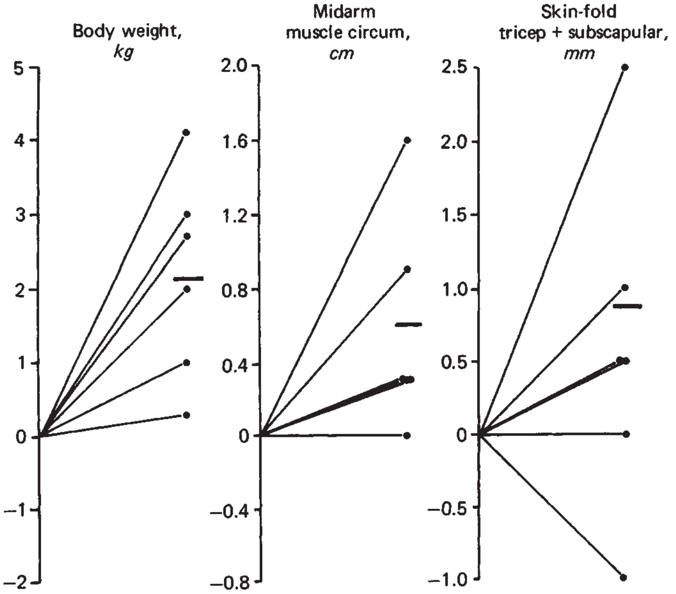

Fig. 6. *Change in body weight, mid-arm muscle circumference, and skinfold thickness during studies in six men ingesting 1.4 g protein/kg body wt diet for 21 to 33 days.* Each *circle* indicates the change in the value obtained at the termination of the study in a given patient compared to the measurement obtained at the onset of the study (Table 1). The *bars* represent the mean increment in values during the course of the six studies. The increment in body weight was significant ($P < 0.02$).

g/kg/day, there was no further increment in nitrogen balance with greater protein intake. These observations suggest that the daily protein requirement for clinically stable patients undergoing CAPD is at least 1.1 g/kg/day. The requirement for protein during CAPD is probably nearer to 1.2 to 1.3 g protein/kg body wt/day based on considerations to account for variability among subjects in the calculation of Recommended Dietary Allowances [42]. These recommendations are consistent with a report

Table 7. Phosphorus intake, output, and balance in patients undergoing CAPD while receiving different protein intakes

	1.0 g/kg body wt					1.4 g/kg body wt				
Patient no.	Diet	Dialysate	Urine	Feces	Balance	Diet	Dialysate	Urine	Feces	Balance
					mg/day					
1	922	327 ± 10	81	588	−73 ± 53					
2	979	214 ± 11	—	452	+314 ± 17	1673	288 ± 9	—	988	+399 ± 56
3	1118	283 ± 14	16	632	+188 ± 42	1689	259 ± 16	—	930	+500 ± 87
4	1036	402 ± 7	—	483	+151 ± 11	2069	443 ± 8	—	710	+914 ± 56
5	1192	326 ± 11	103	189	+574 ± 45	1957	430 ± 11	223	588	+718 ± 20
6						1709	334 ± 7	—	1000	+375 ± 46
7	964	377 ± 13	—	478	+109 ± 24	2395	236 ± 28	—	819	+1340 ± 69
8	1117	336 ± 20	—	456	+325 ± 40					
Mean ± SEM[a]	1047 ± 37[b]	324 ± 23	—	468 ± 53[b]	+227 ± 77	1915 ± 117	332 ± 36	—	839 ± 67	+708 ± 152

Values represent mean or mean ± SEM of data obtained during the entire 14 to 33 days of study.
[a] These figures are the SEM of seven values on the 1.0 and six values on the 1.4 g/kg protein diets.
[b] $P < 0.01$, by paired *t* test from corresponding values obtained with the 1.4 g/kg diet.

Table 8. Calcium intake, output and balance in patients undergoing CAPD while receiving different protein intakes

	1.0 g/kg body wt					1.4 g/kg body wt				
Patient no.	Diet	Net dialysate uptake[a]	Urine	Feces	Balance	Diet	Net dialysate uptake	Urine	Feces	Balance
					mg/day					
2	718	76 ± 7	—	688	+126 ± 56	1186	139 ± 10	—	1166	+158 ± 23
3	1035	134 ± 14	2	1130	+37 ± 37	1076	72 ± 6	—	827	+320 ± 75
4	605	77 ± 3	—	696	−14 ± 15	1532	46 ± 4	—	1198	+379 ± 42[b]
5	837	−22 ± 7	17	452	+348 ± 22	1211	3 ± 4	33	644	+537 ± 48
6						1340	74 ± 14	—	2146	−731 ± 76
7	870	190 ± 14	—	969	+90 ± 14	1791	68 ± 12	—	1336	+523 ± 137
8	546	146 ± 17	—	605	+86 ± 41					
Mean ± SEM[c]	769 ± 74[d]	100 ± 30	—	753 ± 110	+112 ± 51[d]	1356 ± 108	67 ± 18	—	1220 ± 213	+198 ± 194

Values represent mean or mean ± SEM of data obtained during the entire 14 to 33 days of study.
[a] Net dialysate uptake represents the total inflow calcium less total calcium in effluent dialysate.
[b] Received 0.25 μg 1,25 dihydroxycholecalciferol during the last 12 days of the study.
[c] These figures are the SEM of six values on the 1.0 and six values on the 1.4 g/kg protein diets.
[d] $P < 0.05$ by paired *t* test from corresponding values obtained with 1.4 g/kg protein diet.

of neutral or positive balance in seven of eight patients undergoing CAPD and fed 1.2 g protein/kg/day [43]. A daily protein intake above 1.2 to 1.3 g protein/kg/day might be indicated for wasted patients, those receiving less energy, and those with intercurrent illnesses, particularly peritonitis during which peritoneal losses of protein are increased [24]. For an obese individual, protein intake probably should be calculated for normal body weight adjusted for age, height, and sex.

The findings of the present study (Table 4) also indicate that in CAPD patients the SUN concentrations are rather low. Thus, despite the high protein intake of 108 to 119 g/day with the 1.4 g/kg/day diet, the SUN was only 91.3 ± 7.0 mg/dl; with the 1.0 g/kg diet which provided 62 to 85 g/day of protein, the mean SUN was even lower, 67.4 ± 5.5 mg/dl. These relatively low SUN levels with CAPD were due to a low urea nitrogen appearance (Table 4), which comprises a smaller fraction of total nitrogen output than in normal individuals or hemodialysis patients eating similar amounts of protein. The low urea nitrogen appearance in the CAPD patients is probably due to the quantity of protein, amino acids, and peptides lost in dialysate [26] as well as the positive nitrogen balance.

Serum potassium levels were normal or in the lower range of normal in most patients. These findings were present despite the rather high potassium intake, particularly with the higher protein diet. The relatively low serum potassium levels were not due to a high peritoneal clearance of potassium which was 65 ± 2.5 liters/week; this level is lower than our calculated values of 80 to 90 liters/week for potassium dialysance during hemodialysis carried out with a dialysate potassium of 2.0 mEq/liter for 4 hr thrice weekly. The low serum potassium appears to be related to the anabolic state and positive balance in many of the patients and to the high fecal potassium losses. Fecal potassium excretion was 19 ± 1.2 mEq/day or 26 ± 1.3% of dietary intake, a percentage greater than the reported value of 15 ± 1.1% in individuals with normal renal function [44]. The percent loss was similar to the 30% reported in nondialyzed chronically uremic patients [15, 45] and the 37% in those undergoing twice-weekly hemodialysis [45]. However, serum potassium levels were generally lower in the CAPD patients than in the uremic patients [15]. The reasons for the increased fecal potassium losses in renal failure have been studied in experimental animals [46, 47]; increased activity of Na-K-ATPase and enhanced sodium absorption and potassium excretion were found in the colon of rats with renal insufficiency and fed high potassium intakes.

For individuals with normal renal function, potassium and nitrogen are found in a constant ratio in soft tissue, and the relative magnitudes of gain or loss of these two elements during balance studies are similar to their ratio in soft tissue. The reported ratio for loss of potassium (mEq) to that of nitrogen (g) is 3.0:1.0 during fasting [14]. The ratios of potassium/nitrogen were higher in the present studies; thus, the ratio of potassium balances to those of nitrogen averaged 6.7:1.0, (Tables 4 and 5 and Fig. 1), and the slope between potassium and nitrogen balances was 4.4. The ratio averaged 8.0:1.0 after the balances were adjusted for unmeasured losses of 0.8 g/day for nitrogen (vide supra) and 2 mEq/day for potassium [48]. The higher ratios of potassium to nitrogen and the great variance of the ratio in the CAPD patients may reflect a greater and more variable depletion of soft tissue stores of potassium in dialysis patients [49, 50].

Dietary potassium intake varied according to protein intake and therefore was not an independent variable. Also, potassium balance correlated with nitrogen balance. For this reason, no conclusion can be reached regarding dietary potassium requirements.

The value for net magnesium removed during peritoneal dialysis, 46 ± 8 mg/day, is greater than that reported by Parker and Nolph [51]; this difference probably is related to higher serum magnesium levels in the present study. With the exception of patient six, net intestinal absorption of magnesium was positive and the fraction of net absorption was similar to that reported in patients with stable chronic renal failure [16, 28]. The presence of normal net intestinal absorption of magnesium in most patients and the use of a dialysate magnesium concentration of 1.85 mg/dl probably accounts for the high serum magnesium levels in the CAPD patients. The lower serum levels reported elsewhere may have arisen because of lower dietary magnesium intake [51]. A reduction in the dialysate concentration of magnesium to 1.2 to 1.5 mg/dl (1.0 to 1.2 mEq/liter) might result in serum magnesium concentrations that are closer to normal.

It has been claimed that hyperphosphatemia may be prevented more easily in uremic patients undergoing CAPD than in those treated with hemodialysis [3]. The present report does not support this contention because the average serum phosphorus concentrations were 5.0 mg/dl or above during six of the 13 studies. The dietary phosphorus intake was high in the CAPD studies, averaging 1.0 and 1.9 g/day with the low and high protein diets. Despite the ingestion of substantial quantities of aluminum hydroxide by the CAPD patients; net phosphorus absorption was similar or greater than that in nondialyzed uremic patients who were not receiving phosphate binders (Fig. 4). Thus, the effects of the phosphate-binding antacids are largely offset by the high phosphate diet ingested by some CAPD patients.

Net absorption of calcium (dietary intake minus fecal losses) exceeded 200 mg/day in five of nine studies with the patients eating more than 800 mg of calcium/day (Table 8 and Fig. 5). Net calcium absorption was high in these patients compared to uremic patients ingesting similar quantities of calcium. The net calcium transfer from peritoneal dialysate was 84 ± 18 mg/day, a value greater than that extrapolated from the data of Parker and Nolph [51]. The net calcium transfer from dialysate was correlated inversely with serum calcium levels. The observation of high net dietary absorption and dialysate absorption of calcium in a substantial number of patients undergoing CAPD raises the possibility that such treatment could lead to continued calcium accumulation with a propensity towards hypercalcemia; indeed, a preliminary report suggests that mild hypercalcemia developed in a substantial fraction of patients treated with CAPD [52].

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References

1. Popovich RP, Moncrief JW, Nolph KD, Ghods AJ, Twardowski ZJ, Pyle WK: Continuous ambulatory peritoneal dialysis. *Ann Intern Med* 88:449–456, 1978
2. Oreopoulos DG, Robson M, Faller B, Ogilvie R, Rapoport A, DeVeber GA: Continuous ambulatory peritoneal dialysis: A new era in treatment of chronic renal failure. *Clin Nephrol* 11:125–128, 1979
3. Nolph KD, Sorkin M, Rubin J, Arfania D, Prowant B, Fruto L, Kennedy D: Continuous ambulatory peritoneal dialysis: Three-year experience at one center. *Ann Intern Med* 92:609–613, 1980
4. Kopple JD: Dietary requirements, in *Clinical Aspects of Uremia and Dialysis,* edited by Massry SG, Sellars A, Springfield, Illinois, Charles C. Thomas, 1976, p. 453
5. Banzal VK, Popli S, Pickering J: Protein calorie malnutrition and cutaneous anergy in hemodialysis maintained patients. *Am J Clin Nutr* 33:1608–1611, 1980
6. Blumenkrantz MJ, Kopple JD, Gutman RA, Chan YK, Barbour GL, Roberts C, Shen FH, Gandhi VS, Tucker CT, Curtis FK, Coburn JW: Methods for assessing nutritional status of patients with renal failure. *Am J Clin Nutr* 33:1567–1585, 1980

7. Ahmad S, Gallagher NM, Shen F: Intermittent peritoneal dialysis: Status reassessed. *ASAIO* 25:86–89, 1979
8. Blumenkrantz MJ, Schmidt RW: Managing the nutritional concerns of the patient undergoing peritoneal dialysis, in, *Peritoneal Dialysis,* edited by Nolph KD, The Hague, Martinus Nijhoff, 1981, p. 275
9. Rubin J, Flynn MA, Nolph KD: Total body potassium—A guide to nutritional health in patients undergoing continuous ambulatory peritoneal dialysis. *Am J Clin Nutr* 34:94–98, 1981
10. Brozek J, Grande JF, Anderson JT, Keys A: Densitometric analysis of body composition: Revision of some quantitative assumptions. *Ann NY Acad Sci* 110:113–140, 1963
11. Frisancho AR: Triceps skin fold and upper arm muscle size norms for assessment of nutritional status. *Am J Clin Nutr* 27:1052–1058, 1974
12. Miller CE: Low-intensity spectrometry of the gamma radiation emitted by human beings, in *International Conference on the Peaceful Uses of Atomic Energy* Geneva, United Nations 23:113–122, 1958
13. Lavender S, Hilton PJ, Jones NF: The measurement of glomerular filtration rate in renal disease. *Lancet* 2:1216–1218, 1969
14. Reifenstein EC Jr, Albright F, Wells SL: The accumulation, interpretation, and presentation of data pertaining to metabolic balances, notably those of calcium, phosphorus, and nitrogen. *J Clin Endocrinol* 5:367–395, 1945
15. Kopple JD, Coburn JW: Metabolic studies of low protein diets in uremia: N and K balances. *Medicine (Baltimore)* 52:583–594, 1973
16. Kopple JD, Coburn JW: Metabolic studies of low protein diets in uremia. Calcium, phosphorus and magnesium. *Medicine (Baltimore)* 52:597–607, 1973
17. Grodstein G, Blumenkrantz MJ, Kopple JD: Nutritional and metabolic response to catabolic stress in uremia. *Am J Clin Nutr* 33:1411–1416, 1980
18. Oreopoulos DG, Hobson M, Izatt S, Clayton S, deVeber GA: A simple and safe technique for continuous ambulatory peritoneal dialysis (CAPD). *ASAIO* 24:484–489, 1978
19. Gornall AG, Bardawill CJ, David MM: Determination of serum proteins by means of the biuret reaction. *J Biol Chem* 177:751–766, 1949
20. Rodkey FL: Direct spectrophotometric determination of albumin in human serum. *Clin Chem* 11:478–487, 1965
21. Mancini G, Carbonara AO, Heremans JF: Immunochemical quantitation of antigens by single radial immunodiffusion. *Immunochemistry* 2:235–254, 1965
22. Bowes CF, Church HN: *Food Values of Portions Commonly Used* (11th ed). Philadelphia, J. B. Lippincott Co., 1970, pp. 5–144
23. Grodstein GP, Blumenkrantz MJ, Kopple JD, Moran JK, Coburn JW: Glucose absorption during continuous ambulatory peritoneal dialysis. *Kidney Int* 19:564–567, 1981
24. Blumenkrantz MJ, Gahl GM, Kopple JD, Kamdar AJ, Jones MR, Kessel M, Coburn JW: Protein loss during peritoneal dialysis. *Kidney Int* 19:593–602, 1981
25. Kopple JD, Blumenkrantz MJ, Jones MR, Moran JK, Coburn JW: Plasma amino acid levels and amino acid losses during continuous ambulatory peritoneal dialysis *Am J Clin Nutr*, in press
26. Blumenkrantz MJ, Kopple JD, Moran JK, Grodstein GP, Coburn JW: Nitrogen and urea metabolism during continuous ambulatory peritoneal dialysis. *Kidney Int* 20:78–82, 1981
27. Hill MA (ed): *BMDP Users Digest.* Department of Biomathematics, University of California, Los Angeles, 1979
28. Clarkson EM, McDonald SJ, deWardener HE, Warren R: Magnesium metabolism in chronic renal failure. *Clin Sci* 28:107–115, 1965
29. Coburn JW, Hartenbower DL, Brickman AS, Massry SG, Kopple JD: Intestinal absorption of calcium, magnesium and phosphorus in chronic renal insufficiency, in *Calcium Metabolism in Renal Failure and Nephrolithiasis,* edited by David DS, New York, John Wiley and Sons, 1977, pp. 77–109
30. McDonald SJ, Clarkson EM, deWardener HE: The effect of a large intake of calcium citrate in normal subjects and patients with chronic renal failure. *Clin Sci* 26:27–39, 1964
31. Clarkson EM, McDonald SJ, deWardener HE: The effect of a high intake of calcium carbonate in normal subjects and patients with chronic renal failure. *Clin Sci* 30:425–438, 1966
32. Calloway DH, Odell ACF, Margen S: Sweat and miscellaneous nitrogen losses in human balance studies. *J Nutr* 101:775–786, 1971
33. Ginn HE, Frost A, Lacy WW: Nitrogen balance in hemodialysis patients. *Am J Clin Nutr* 21:385–393, 1968
34. Ginn HE: Nutritional aspects of chronic renal dialysis. *S Med J* 62:1471–1476, 1969
35. Kopple JD, Shinaberger JH, Coburn JW, Sorensen MK, Rubini ME: Optimal dietary protein treatment during chronic hemodialysis. *Trans Am Soc Artif Int Org* 15:302–308, 1969
36. Kopple JD, Coburn JW, Rubini ME: Nitrogen requirements in chronic uremia, in *Uremia, An International Conference on Pathogenesis, Diagnosis and Therapy,* edited by Kluthe R, Berlyne G, Burton B, Stuttgart, Germany, Georg Thieme Verlag, 1972, pp. 271–282
37. Borah MF, Schoenfeld PY, Gotch FA, Sargent JA, Wolfson M, Humphreys MH: Nitrogen balance during intermittent dialysis therapy of uremia. *Kidney Int* 14:491–500, 1978
38. DeSanto NG, Capodicasa G, Senatore R, Cicchetti T, Cirillo D, Damiano M, Torella R, Giugliano D, Improta L, Giordano C: Glucose utilization from dialysate in patients on continuous ambulatory peritoneal dialysis. *Int J Artif Org* 2:119–124, 1979
39. Wathen RL, Keshaviah P, Hommeyer P, Cadwell K, Comty CM: The metabolic effects of hemodialysis with and without glucose in the dialysate. *Am J Clin Nutr* 31:1870–1875, 1978
40. Ward RA, Shirlow MJ, Hayes JM, Chapman GV, Farrell PC: Protein catabolism during hemodialysis. *Am J Clin Nutr* 32:2443–2449, 1979
41. Keys A, Brozek J, Henschel A, Mickelsen O, Taylor HL: *The Biology of Human Starvation,* Minnesota Laboratory of Physiological Hygiene, Minneapolis University Minnesota Press, 1950
42. Committee on Dietary Allowances: *Recommended Dietary Allowances.* Washington, D.C., National Academy of Sciences, 1980, pp. 1–15
43. Giordano C, DeSanto NG, Pluvio M, DiLeo VA, Capodicasa G, Cirillo D, Esposito R, Daminao M: Protein requirement of patients on CAPD: A study on nitrogen balance. *Int J Artif Org* 3:11–14, 1980
44. Dempsey EF, Carroll EL, Albright F, Henneman PH: A study of factors determining fecal electrolyte excretion. *Metabolism* 7:108–118, 1958
45. Hayes CP Jr, McLeod MI, Robinson RR: An extrarenal mechanism for the maintenance of potassium balance in severe chronic renal failure. *Trans Assoc Am Physicians* 80:207–216, 1967
46. Bastl C, Hayslett JP, Binder HJ: Increased large intestinal secretion of potassium in renal insufficiency. *Kidney Int* 12:9–16, 1977
47. Hayslett JP, Myketey N, Binder HJ, Aronson PS: Mechanism of increased potassium secretion in potassium loading and sodium deprivation. *Am J Physiol* 239:F378–F382, 1980
48. Freyberg RH, Grant RL: Loss of minerals through the skin of normal humans when sweating is avoided. *J Clin Invest* 16:729–731, 1937
49. Bilbrey GL, Carter NW, White MG, Schilling JF, Knochel JP: Potassium deficiency in chronic renal failure. *Kidney Int* 4:423–430, 1973
50. Butkus DE, Alfrey AC, Miller NL: Tissue potassium in chronic dialysis patients. *Nephron* 13:314–324, 1974
51. Parker A, Nolph KD: Magnesium and calcium mass transfer during continuous ambulatory peritoneal dialysis. *Trans Am Soc Artif Int Org* 26:194–196, 1980
52. Kurtz SB, McCarthy JT, Kumar K: Hypercalcemia in continuous ambulatory peritoneal dialysis patients (*abstract*). *Clin Res* 29:411A, 1981