Nephron 1991;59:33–40

0028–2766/91/0591–0033$2.75/0

Anthropometry Underestimates Body Protein Depletion in Haemodialysis Patients

Hugh C. Rayner[a], *Daniel B. Stroud*[b], *Karen M. Salamon*[c], *Boyd J.G. Strauss*[d], *Napier M. Thomson*[a], *Robert C. Atkins*[a], *Mark L. Wahlqvist*[e]

Departments of [a] Nephrology, [b] Medical Physics, [c] Dietetics, and [d] Clinical Nutrition and Metabolism, Monash Medical Centre, Prince Henry's Campus, and [e] Department of Medicine, Monash University, Melbourne, Victoria, Australia

Key Words. Haemodialysis · Anthropometry · Glucocorticoids · Nitrogen · Body mass index · Nutritional status, haemodialysis patients

Abstract. The body composition of 62 haemodialysis patients (41 males) and 63 controls (30 males) was assessed using anthropometry and in vivo neutron activation analysis of body nitrogen. There was no significant difference between patients and controls in body mass index (BMI) and percentage body fat. Arm muscle circumference was significantly reduced in males. Lean body mass was strongly correlated with body nitrogen in controls (r = 0,951) but less so in patients (r = 0,876). The mean standardised body nitrogen index (NI) was reduced in male patients by 13% (95% confidence interval –9 to –17%) and in females by 4% (95% confidence interval +4 to –12%). Of the 16 patients with a NI below the control range, arm muscle circumference was below the control range in only 3 and BMI less than 18 kg/m² in 2. NI was correlated negatively with the duration of renal replacement therapy, duration of haemodialysis, the number of previous failed transplants and the total dose of steroids received but not with current energy or protein intakes. Steroid dose was the only significant independent variable. Anthropometry underestimates body protein depletion in haemodialysis patients and the degree of protein loss is related to the cumulative dose of corticosteroids previously received.

Introduction

Wasting is an important clinical problem in patients with renal failure and on haemodialysis [1]. Patients with severe chronic renal failure have a reduction in lean body mass and fat accompanied by an increase in body water [2]. When haemodialysis is commenced, body water is removed and lean body mass tends to increase [3]. However, even in apparently well patients on dialysis, anthropometric evidence of wasting may still be present [4, 5] and this has been associated with an increased risk of mortality [6].

An important component of wasting is the loss of body protein. This results from a persistently negative nitrogen balance, which may be due to an inadequate nutrient intake, impaired anabolism or excessive catabolism of body protein [7]. The relative importance of nutritional and metabolic factors in the development of wasting in haemodialysis patients is not known.

Body protein is most accurately measured by in vivo neutron activation analysis (IVNAA) of body nitrogen [4]. As yet, studies on only small numbers of patients using this technique have been published. Cohn et al. [8] found a reduction in total body protein in 15 haemodialysis patients, but this did not reach statistical significance. Williams et al. [9] found a significant 9% reduction in total body protein in 43 patients dialysed for up to 5 years, but normal values in 8 patients dialysed for over 5 years.

Allman et al. [27] have recently reported a significant reduction in body protein in 18 patients, including 4 who had been dialysed for over 5 years.

We have measured the body composition of a large unselected population of long-term haemodialysis patients using anthropometry and IVNAA and have correlated the results with possible causative factors of body protein depletion.

Patients and Methods

Patient Population

The study was approved by the Ethics Committee of the Monash Medical Centre. Sixty-two of the 69 patients on maintenance haemodialysis under the supervision of the Prince Henry's Campus of the Monash Medical Centre agreed to participate in the study. All had been on haemodialysis for at least 1 month and had had no intercurrent illness in the previous month. Patients were dialysed for 4–5 h, 3 times per week, using hollow fibre dialysers containing cuprophane (55 patients) or cellulose acetate membranes. Glucose-free acetate – (45 patients) or bicarbonate-buffered dialysate was used and blood was pumped at a rate of 200–250 ml/min.

Patients routinely took aluminium-, magnesium- and/or calcium-containing oral phosphate-binding agents, ferrous sulphate, folic acid and vitamin supplements. No patients received erythropoietin. Low protein diets had been used by some patients prior to the commencement of dialysis, but only temporarily to relieve uraemic symptoms.

Twenty-seven patients had previously had kidney transplants. Before 1980, the immunosuppression regimen was 'high' dose prednisolone (initially 100 mg/day) with pulses of intravenous methylprednisolone (1 g/day for 3 days) for episodes of acute rejection. Between 1980 and 1982, 'low' dose prednisolone was used (initially 30 mg/day) with 0.5 g pulses of methylprednisolone for 3 days. From 1983, cyclosporine A and 'low' dose prednisolone with or without azathioprine was used, with 0.5 g pulses of methylprednisolone.

The total dose of glucocorticoids received both before and after the commencement of dialysis was recorded from the prescription charts. Doses were expressed as equivalent of prednisolone [10]: 1 g prednisolone = 0.8 g methylprednisolone = 4 g hydrocortisone.

The quality of life was assessed by the dialysis nursing staff using the Karnofsky scale [11].

Biochemical and Haematological Measurements

After the longest interdialytic period, blood was taken prior to dialysis for the measurement of serum albumin, urea, creatinine, calcium, phosphate, alkaline phosphatase, intact parathyroid hormone, aluminium, magnesium, ferritin, electrolyte and haemoglobin concentrations, and lymphocyte count.

Dietary Assessment

Fifty-two of the 62 patients completed a 4-day (Wednesday to Saturday) food and drink diary and were interviewed by an experienced renal dietitian (K.S.). Energy and protein intake were calculated using 'Nutritionist III' software. Energy intake was expressed as a percentage of the Australian energy allowance recommended for people of the same sex, age and body weight [12].

Body Composition Measurements

Skin fold thickness was measured using a Harpenden caliper at the biceps, triceps, subscapular and supra-iliac regions and percentage body fat was calculated according to Durnin and Womersley [13]. Arm muscle circumference was calculated as mid-arm circumference – (3.14 × triceps skinfold thickness); body mass index as weight/height^2, and lean body mass as weight × (1–%fat/100).

Body nitrogen was measured using in vivo prompt gamma neutron activation analysis [14, 15]. Patients lay supine on a couch and were exposed from below to a single ^{252}Cf neutron source for 1,000 s giving an estimated dose of less than 0.15 mSv. The 24 × 43 cm beam was centred midway between the umbilicus and the iliac crests. Prompt gamma emissions were detected by two NaI detectors, one each side of the patient. Nitrogen and hydrogen gamma emissions were counted and hydrogen used as an internal standard [16].

The ratio of nitrogen to hydrogen gamma counts is proportional to the ratio of the amounts of these elements in the body. Since the detecting efficiencies for nitrogen and hydrogen gammas are different, the ratio of nitrogen to hydrogen counts from the patient has to be corrected against a urea phantom containing known amounts of nitrogen and hydrogen. Phantom counts were performed before and after each patient session.

Body nitrogen content was then calculated using the following equation:

$$\text{Body N content} = \text{body H content} \times \text{patient} \frac{\text{N counts}}{\text{H counts}} \times \frac{\text{phantom} \frac{\text{N content}}{\text{H content}}}{\text{phantom} \frac{\text{N counts}}{\text{H counts}}},$$

where body hydrogen content = 0.10 × body weight [17]. Body protein content = 6.25 × body nitrogen. The coefficient of variation of phantom studies was ±4%.

It was not possible to perform anthropometry and body nitrogen measurements at a constant time in relation to the haemodialysis schedule. However, measurements of body nitrogen by IVNAA and of body fat by anthropometry are theoretically independent of body water.

One region of the body was routinely scanned and the results extrapolated to the whole body. The abdomen was chosen since the proximal musculature is predominantly affected in metabolic and uraemic myopathy [18]. Scanning one region only enables a low counting error to be achieved with the minimum dose of radiation. However, the ratio of nitrogen to hydrogen may not be the same in all regions of the body [16]. To test this, 12 patients had further 1,000-second counts performed with the beam centred midway between the iliac crests and tibial tuberosities. The values of total body nitrogen calculated from each region were compared.

Control Data for Body Composition

Thirty male and 33 female healthy volunteers (hospital staff and patients' spouses) with a body mass index between 18 and 30 kg/m^2 were studied by anthropometry and neutron activation analysis as above.

Respiratory Muscle Function

As a measure of truncal muscle function, maximum inspiratory pressure at residual volume and maximum expiratory pressure were

measured in a random sample of 19 volunteers and 19 patients using standard techniques [19]. Results were expressed as a percentage of the predicted value for sex and age [19].

Statistics

Data were analysed using 'CSS' software. Means or medians were used as appropriate. Relevant variables were correlated using linear regression analysis and then entered stepwise in a multiple linear regression analysis.

Results

Clinical Details

Forty-one male and 21 female patients were studied. The mean age for males was 47.7 years (range 21–76) and for females 51.7 years (24–73). The underlying renal disease was: biopsy-proven glomerulonephritis in 25; presumed glomerulonephritis in 13; polycystic kidney disease in 9; reflux nephropathy in 5; diabetes mellitus in 2, and miscellaneous in 8. Twenty-three patients (19 men) dialysed at home, 28 (15 men) attended a limited care satellite unit and 11 (7 men) were dialysing in the hospital while training for future home or satellite dialysis. Patients had a good quality of life, the mean Karnofsky score being 90 (range 60–100) for men and 92 (80–100) for women.

Details of previous renal replacement therapy are shown in table 1. Twenty-three patients had had periods of peritoneal dialysis of between 2 and 67 months per patient (median 26 months). Twenty-seven (19 males) had received one or more renal transplants, with periods of transplant function between 0 and 108 months per patient (median 3 months). Four patients had had steroid therapy for underlying disease. Three patients were on steroids at the time of the study and 28 others had ceased them between 3 and 171 months previously (median 57.5 months). For those patients who had received steroids, the median total dose was equivalent to 20.7 g prednisolone (range 1.5–72.7 g) in males and 13.7 g (3.1–56.5) in females ($p = n.s.$).

Two patients had developed marked proximal muscle weakness at the time of transplantation which had been attributed to steroid therapy. Neither had symptoms of weakness at the time of the study. One patient had had severe polyneuropathy with proximal muscle weakness 1 year previously but proximal muscle strength had fully recovered and he was performing part-time manual work at the time of the study. Three patients had had mutliple abdominal operations for bowel obstruction due to intra-abdominal adhesions.

Table 1. Total median duration (months) of renal replacement therapy and total median duration (months) of haemodialysis for male and female patients

	Males (n = 41)	Females (n = 21)
Renal replacement therapy	56 (1–192)	67 (5–147)
Haemodialysis	53 (1–174)	28 (3–146)

The ranges are given in parentheses.

Biochemistry

The mean (±SD) predialysis serum urea concentration was 30.0 ± 8.0 mmol/l (normal range < 9 mmol/l).

Six patients had biochemical or radiological evidence of hyperparathyroidism. Two others had undergone subtotal parathyroidectomy 1 month prior to the study. Eight patients were taking $1,25(OH)_2$ vitamin D_3 supplements. One patient was having iron chelation therapy with desferrioxamine for a serum ferritin concentration of 1,214 µg/l (normal range < 300 µg/l).

The mean (±SD) serum aluminium concentration was 2.1 ± 1.1 µmol/l (normal range < 0.8 µmol/l). One patient was having aluminium chelation therapy with desferrioxamine but had no symptoms of aluminium toxicity.

The mean (±SD) serum magnesium concentration was 1.26 ± 0.4 mmol/l (normal range 0.8–1.05 mmol/l), serum albumin 42.0 ± 4.7 g/l (normal 35–45 g/l), haemoglobin 9.3 ± 2.8 g/dl and lymphocyte count 1.7 ± 0.5 $\times 10^9$/l.

Dietary Assessment

Fifty-two patients (34 males) completed a 4-day food and drink diary. Mean energy intake (±SD) was 1,595 ± 459 kcal/day, equivalent to 74 ± 17% of the recommended daily allowance. Mean protein intake (±SD) was 1.0 ± 0.3 g/kg body weight/day. Predialysis serum urea concentration was significantly correlated with daily protein intake per kilogram body weight ($r = 0.345$, $p = 0.01$).

Body Composition

Results of anthropometric and IVNAA measurements are given in table 2. Patients were older than controls, this being significant in females. Female patients were also significantly shorter than controls. There was no significant difference in body mass index or percentage body fat measured by anthropometry. Arm muscle cir-

Table 2. Body composition data on 63 controls (30 males) and 62 patients (41 males)

		Controls	Patients	p
Age, years	Males	41.6 ± 2.2	47.7 ± 2.3	
	Females	42.9 ± 1.8	51.7 ± 3.1	= 0.01
Height, m	Males	1.76 ± 0.01	1.73 ± 0.01	
	Females	1.61 ± 0.01	1.57 ± 0.01	= 0.05
Body mass index, kg/m²	Males	24.7 ± 0.4	24.2 ± 0.7	
	Females	23.5 ± 0.5	25.4 ± 1.3	
% fat	Males	21.0 ± 1.0	20.2 ± 1.2	
	Females	31.2 ± 0.8	30.9 ± 1.8	
Albumin, g/l	Males	(35–45)	43.0 ± 0.7	
	Females		40.0 ± 0.8	
Arm muscle circumference, cm	Males	27.5 ± 0.6	25.5 ± 0.4	= 0.006
	Females	22.7 ± 0.4	23.6 ± 0.8	
Total body nitrogen, kg	Males	1.93 ± 0.06	1.58 ± 0.05	< 0.0001
	Females	1.29 ± 0.03	1.10 ± 0.04	= 0.002
Nitrogen index	Males	1.00 ± 0.02	0.87 ± 0.02	< 0.0001
	Females	1.00 ± 0.02	0.96 ± 0.04	NS

Values are means ± SEM. Patients were compared with controls using Student's t test. Albumin was not measured in the controls; the normal range for the laboratory is quoted.

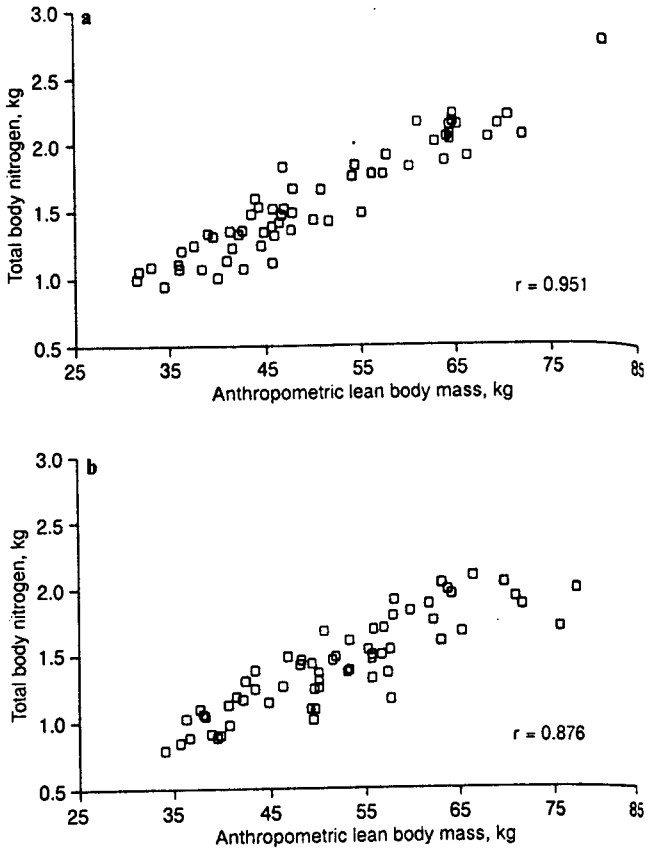

Fig. 1. The relationship between body nitrogen measured by IVNAA and lean body mass measured by anthropometry in controls (**a**) and patients (**b**).

cumference was significantly lower in male patients than controls but not in females. Body nitrogen content was significantly lower in both male and female patients.

In view of the differences in age and height between patients and controls, body nitrogen values were standardised as follows. Multiple linear regression analyses of height and age against body nitrogen were performed for male and female controls. For males, only height was a significant variable ($p < 0.001$); for females both height and age were significant ($p < 0.001$, $p < 0.01$ respectively). The regression equations for these relationships were: for males, predicted body nitrogen (kg) = height (m) × 2.98 (± 0.50 SE) − 3.32, $r = 0.747$, and for females, predicted body nitrogen (kg) = height (m) × 1.59 (± 0.29) − age (years) × 0.0064 (± 0.0023) − 1.02, $r = 0.733$.

A nitrogen index was then calculated: nitrogen index = (measured body nitrogen)/(predicted body nitrogen).

The range of nitrogen indices for male controls was 0.81–1.27 and for females 0.81–1.28, with a mean for both of 1.00. The mean nitrogen index was reduced in male patients by 13% (95% confidence intervals = −9 to −17%) and in females by 4% (95% confidence intervals = +4 to −12%).

To test the validity of using the results from one region to calculate the nitrogen content of the whole body, 12 patients had scans performed at two sites. The mean (± SEM) total body nitrogen content estimated from measurements made under the abdomen was 1.31 ± 0.11 kg and under the thighs was 1.28 ± 0.11 kg (p = n.s.).

Comparison of Methods of Assessing Body Protein

In controls, body nitrogen measured by IVNAA was strongly correlated with lean body mass measured by anthropometry ($r = 0.951$; fig. 1a). The correlation was less strong in patients ($r = 0.876$), with many having lower body protein contents than expected from their anthropometric lean body mass (fig. 1b). The serum albumin concentration in patients was not significantly correlated with nitrogen index (males $r = 0.128$, females $r = 0.171$, p = n.s.).

The clinical value of a method depends on its ability to detect abnormalities in individuals rather than in groups of patients. Setting 0.80 as the lower limit of the normal range for nitrogen index, 16 patients (13 males) had an

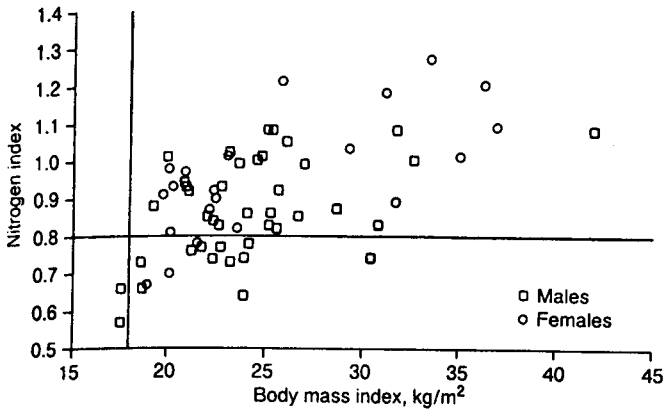

Fig. 2. The relationship between nitrogen index and body mass index. The broken lines indicate the lower limits of the ranges of the nitrogen index and body mass index for controls.

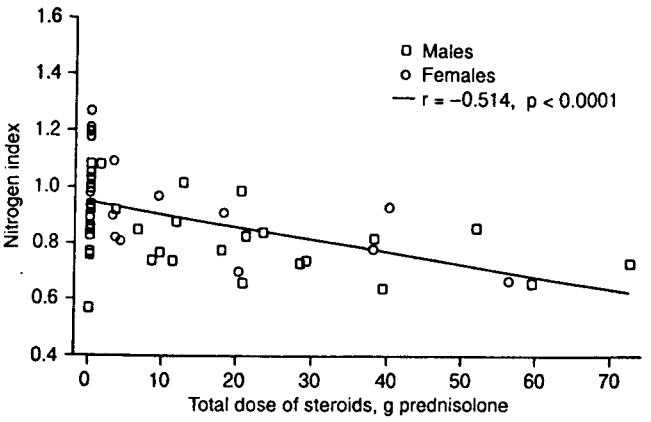

Fig. 3. The relationship between nitrogen index and the total dose of corticosteroids received, expressed as an equivalent dose of prednisolone.

abnormal nitrogen index. Of these, 6 had an arm muscle circumference of less than the 5th percentile for age and sex [20] and in only 3 was this below the control group range for the same sex. No patients had a low arm muscle circumference and a normal nitrogen index.

Figure 2 shows a scattergram of nitrogen index against body mass index. Only 2 patients were abnormal by both measures. 14 patients had body mass indices above the lower limit of the controls but abnormally low nitrogen indices. One patient, who had previously suffered from severe polyneuropathy, had a nitrogen index of 0.74 but a body mass index in the obese range (30.4 kg/m²).

Respiratory Muscle Strength Measurements

Nineteen of the normal volunteers and 19 patients had measurements of respiratory muscle strength. The nitrogen index was significantly lower in the patients (controls mean ± SEM = 0.96 ± 0.02, patients = 0.85 ± 0.03, $p = 0.01$). However, there was no difference in maximum inspiratory pressure (controls mean ± SEM = 88 ± 8% predicted, patients = 82 ± 7%) or maximum expiratory pressure (controls mean ± SEM = 78 ± 5% predicted, patients = 70 ± 3%).

Factors Associated with Body Nitrogen Depletion

Mean body nitrogen index was not significantly different in patients dialysed at home (0.88), at a satellite unit (0.91) or in the centre (0.92). Correlations were made between variables that may have affected body composition and nitrogen index, body mass index, arm muscle circumference and serum albumin. The strongest correlations were found with the nitrogen index (table 3), being statistically significant with the duration of renal replacement therapy, duration of haemodialysis, duration of transplant function, number of transplants performed and the total dose of steroids received. Correlations between nitrogen index and age, serum intact parathyroid hormone concentration, dietary energy intake and protein intake were not statistically significant. When the significant variables were entered in a multiple linear regression analysis against the nitrogen index, the only significant independent variable was the total dose of steroids received. Figure 3 shows the relationship be-

Table 3. Correlations between the nitrogen index and factors that may have affected body composition

	r	p
Age	0.095	0.46
Energy intake, % recommended dietary allowance	−0.156	0.27
Protein intake, g/kg/day	−0.147	0.30
Immunoreactive parathyroid hormone, µmol/l	0.079	0.59
Duration of renal replacement therapy	−0.365	0.004
Duration of haemodialysis	−0.312	0.013
Duration of peritoneal dialysis	0.163	0.21
Duration of transplant function	−0.333	0.008
Number of transplants	−0.465	< 0.0001
Total dose of steroids	−0.514	< 0.0001

The nitrogen index is corrected for sex and so males and females are analysed together.

tween the nitrogen index and the total dose of steroids received. Of the patients who had not received steroids, only one had a markedly reduced nitrogen index. He had had multiple abdominal operations and episodes of intestinal obstruction due to intra-abdominal adhesions.

Discussion

This study has demonstrated that many apparently healthy haemodialysis patients with anthropometric measurements of lean body mass within the normal range have a significant reduction in body nitrogen when studied using IVNAA. The reduced ratio of nitrogen to hydrogen suggests that body protein is replaced by water and/or fat. Furthermore, measurement of arm muscle circumference in haemodialysis patients is not a reliable guide to body protein mass.

IVNAA is regarded as the most accurate method for determining body protein content [4]. A number of centres have now published data using this technique. Each centre varies slightly in the precise details of the technique used. The validity of the values for total body nitrogen in this study is supported by the similarity of control values to previous reports [21] and their strong correlation with lean body mass measured by anthropometry.

Two assumptions are made in using a single neutron source placed under one region of the body to measure total body nitrogen. Firstly, it is assumed that the ratio of nitrogen to hydrogen in the region studied is representative of the body as a whole. This is supported by the similar values for total body nitrogen calculated from studies under the abdomen and thighs. Secondly, it is assumed that nitrogen and hydrogen are homegeneously distributed throughout the region. Neutrons are captured as they penetrate the body and so tissues deep within the body are exposed to a lower dose of radiation and make a smaller proportional contribution to the gamma emissions. We have demonstrated that inserting a 4-cm layer of paraffin wax beneath a nitrogen phantom causes a reduction in measured nitrogen content of approximately 16% (D Borovnicar, unpublished observations). As the percentage body fat in the control and patient groups was the same in this study, the reduction in body nitrogen in the patients was not due to greater fat attenuation. Furthermore, as most patients with a loss of body protein also tend to have lost body fat, the reduction in nitrogen index will tend to underestimate the actual protein deficit.

A number of factors may have contributed to the depletion of body protein in the patients. The level of physical activity may have been lower in some patients than in controls. However, there was no correlation between the nitrogen index and the quality of life score and those patients who dialysed at home, who were generally the most active, and had the lowest mean nitrogen index.

The role of diet in the depletion of body protein is difficult to determine. Although patients claimed that the dietary diaries were representative of their habitual food intake, they may not have been an accurate reflection of the cumulative food intake over the duration of renal replacement therapy. The lack of a correlation between body nitrogen and current energy or protein intakes suggests that body protein depletion was not solely due to malnutrition. However, relative malnutrition in the setting of catabolic stress may have been an important factor in view of the reduced level of energy intake compared to the recommended daily allowance. Longitudinal studies of body protein during catabolic episodes in patients with and without dietary supplementation are required to investigate this further.

As a large proportion of body protein is present in striated muscle, the reduction in body nitrogen probably indicates a loss of muscle protein. Myopathy is a recognised complication of uraemia and a number of causes have been proposed [22]. One patient had a severe neuropathy that had undoubtedly caused a secondary myopathy. Another had biochemical evidence of iron overload, which has been associated with myopathy [23]. Six patients had biochemical or radiological evidence of mild hyperparathyroidism but none had frank osteomalacia and there was no correlation between body nitrogen and serum intact parathyroid hormone levels.

The factor most strongly correlated with depletion of body protein was previous steroid therapy. This strong correlation does not prove that there is a direct causal link between corticosteroids and protein depletion; steroids may have been associated with other important factors such as complicating illness or episodes of rejection. However, there are good reasons to suggest that the two are causally linked. Firstly, corticosteroids are known to cause muscle necrosis and atrophy [24]. Secondly, two patients with a low body nitrogen had been diagnosed as having steroid myopathy whilst having a functioning kidney transplant. Thirdly, Williams et al. [9] have reported a significant reduction in body protein in patients with functioning transplants on steroid immunosuppression. Fourthly, protein depletion was related to steroid therapy in a dose-dependent manner.

The dose-response relationship with steroids is remarkable in view of the length of time since therapy had been ceased, on average 5 years. In an experimental model of steroid myopathy in rabbits with normal renal function, full recovery of muscle architecture occurred on stopping the drug [25]. Renal failure is known to be associated with an impairment of protein synthesis [7]. It is possible, therefore, that normal recovery of muscle mass was impaired in patients whose transplants had failed. In a longitudinal study of 6 transplant patients, Williams et al. [9] found an increase in body nitrogen and a significant increase in body weight between 10 and 28 months after transplantation, suggesting that recovery from steroid myopathy may occur with maintained transplant function.

Corticosteroids damage all striated muscles, including the intercostal muscles and diaphragm [25]. Despite a significant depletion of body protein in the patients, there was no significant reduction in maximum inspiratory and expiratory pressures. Similar results have been reported in patients on continuous ambulatory peritoneal dialysis, who had normal adductor pollicis muscle function despite significant body protein depletion [26]. However, the tests used in our study only measure peak respiratory pressures and it is possible that increased fatigability to sustained effort may have been present.

The lack of a correlation between the nitrogen index and serum albumin concentration emphasises the independence of tissue and circulating proteins. A complete assessment of nutritional status in dialysis patients should therefore include measurements of both compartments.

In conclusion, this study has demonstrated that IVNAA is a more sensitive method for detecting body protein depletion in haemodialysis patients than anthropometry. IVNAA therefore provides important additional information about the body composition and nutritional status of patients on dialysis.

Acknowledgments

We thank Danny Borovnicar, Robyne Bainbridge and Dr. Sharon Marks for carrying out the body composition studies; Jennifer Fung for performing the respiratory function tests, and Drs John Lambert, Eddy Tai and Prof. Kenneth McNeill for helpful advice.

References

1 Ritz E, Bommer J: Metabolic and endocrine dysfunction in chronic renal failure; in Schreier RW, Gottschalk CW (eds): Diseases of the Kidney, Boston, Little, Brown, 1988, chapt 103.
2 Coles GA: Body composition in chronic renal failure. Q J Med 1972;41:25–47.
3 Blainey JD, Hilton DD: The composition of the body in renal failure. Ann R Coll Surg Engl 1970;47:45–51.
4 Blumenkranz MJ, Kopple JD, Gutman RA, et al: Methods for assessing nutritional status of patients with renal failure. Am J Clin Nutr 1980;33:1567–1585.
5 Talemaitoga AS, Hinton D, Sanders BA, et al: Nutritional status of home haemodialysis patients. Aust NZ J Med 1989;19: 303–309.
6 Degoulet P, Legrain M, Reach I, et al: Mortality risk factors in patients treated by chronic hemodialysis. Nephron 1982;31: 103–110.
7 Mitch WE: Uremia and the control of protein metabolism. Nephron 1988;49:89–93.
8 Cohn SH, Brennan BL, Yasumura S, et al: Evaluation of body composition and nitrogen content of renal patients on chronic dialysis as determined by total body neutron activation. Am J Clin Nutr 1983;38:52–58.
9 Williams ED, Henderson IS, Boddy K, et al: Whole-body elemental composition in patients with renal failure and after transplantation studied using total-body neutron-activation analysis. Eur J Clin Invest 1984;14:362–368.
10 British National Formulary. London, British Medical Association/Pharmaceutical Press, 1989.
11 Karnofsky DA, Burchenal JH: The clinical evaluation of chemotherapeutic agents; in MacLeod CM (ed): Evaluation of Chemotherapeutical Agents. New York, Columbia University Press, 1949, p 191.
12 National Health and Medical Research Council: Recommended Dietary Intakes for Use in Australia. Canberra, Australian Government Publishing Service, 1987.
13 Durnin JVGA, Womersley J: Body fat assessed from total body density and its estimation from skin fold thickness. Br J Nutr 1974;32:77–97.
14 Stroud DB, Borovnicar DJ, Lambert JR, et al: Clinical studies of total body nitrogen in an Australian hospital; in Yasumura S, Harrison JE, McNeill KG (eds): In Vivo Body Composition Studies – Recent Advances. New York, Plenum Press, 1990.
15 Vartsky D, Ellis KJ, Cohn SH: In vivo measurement of body nitrogen by analysis of prompt gammas from neutron capture. J Nucl Med 1979;20:1158–1165.
16 Vartsky D, Prestwich WV, Thomas BJ, et al: The use of body hydrogen as an internal standard in the measurement of nitrogen in vivo by prompt neutron capture gamma-ray analysis. J Radioanalyt Chem 1979;48:243–252.
17 McNeill KG, Mernagh JR, Harrison JE, et al: In vivo measurements of body protein based on the determination of nitrogen by prompt gamma analysis. Am J Clin Nutr 1979;32: 1955–1961.
18 Lazaro RP, Kirshner HS: Proximal muscle weakness in uraemia. Arch Neurol 1980;37:555–558.
19 Clausen JL: Pulmonary Function Testing: Guidelines and Controversies. London, Grune & Stratton, 1984, chapt 17.
20 Frisancho AR: New norms of upper limb fat and muscle areas for assessment of nutritional status. Am J Clin Nutr 1981;34: 2540–2545.
21 Ellis KJ, Yasumura S, Vartsky D, et al: Total body nitrogen in health and disease: Effects of age, weight, height and sex. J Lab Clin Med 1982;99:917–928.

22 Ritz E, Kreusser W, Rambausek M, et al: Myopathy of uremia. Adv Exp Med Biol 1984;178:377–386.
23 Bregman H, Gelfand MC, Winchester JF, et al: Iron-overload-associated myopathy in patients on maintenance haemodialysis: A histocompatibility-linked disorder. Lancet 1980;ii:882–885.
24 Perkoff GT, Silber R, Tyler FH, et al: Studies in disorders of muscle. XII. Myopathy due to the administration of therapeutic amounts of 17-hydroxycorticosteroids. Am J Med 1959;26:891–898.
25 Ellis JT: Necrosis and regeneration of skeletal muscles in cortisone-treated rabbits. Am J Pathol 1956;32:993–1013.
26 Sombolos K, Berkelhammer C, Baker J, et al: Nutritional assessment and skeletal muscle function in patients on continuous ambulatory peritoneal dialysis. Periton Dial Bull 1986;6:53–58.
27 Allman MA, Allen BJ, Stewart PM, et al: Body protein of patients undergoing haemodialysis. Eur J Clin Nutr 1990;44 123–131.

Accepted: October 30, 1990

Prof. R.C. Atkins
Department of Nephrology
Prince Henry's Hospital
St. Kilda Road
Melbourne, Victoria 3004 (Australia)