Original Research Communications

Comparison of five body-composition methods in peritoneal dialysis patients[1–3]

Sharon H Stall, Nancy S Ginsberg, Maria V DeVita, Paul M Zabetakis, Robert I Lynn, Gilbert W Gleim, Jack Wang, Richard N Pierson Jr, and Michael F Michelis

ABSTRACT Body-composition assessment is an important method of evaluating nutritional status in peritoneal dialysis patients. Because body-composition measurement estimates have not been fully validated in this population, we assessed five body-composition methods in 30 well-dialyzed peritoneal dialysis patients. The techniques studied included bioelectrical impedance analysis, dual-energy X-ray absorptiometry, total-body potassium counting, and anthropometry by two techniques. The dialysis patients were matched for age, race, sex, height, weight, and body mass index with 29 healthy control subjects in our laboratory database. By $5 \times 2 \times 2$ analysis of variance, significant differences were found between results by modality ($P < 0.0001$) as well as by sex, with women having an increased percentage of fat ($P < 0.0001$). However, there was no significant intermethod difference by condition (peritoneal dialysis or control). That is, although significantly different percentage fat values were found between the body-composition techniques, this variability was independent of whether the measurement was made on control or peritoneal dialysis patients. Despite the differences between modalities, all techniques were found to correlate significantly with each other ($P < 0.01$ or better for men and $P < 0.001$ or better for women). Our experience shows that these routine techniques for measuring body composition can be readily applied to stable peritoneal dialysis patients. *Am J Clin Nutr* 1996;64:125–30.

KEY WORDS Peritoneal dialysis, body composition, bioelectrical impedance, dual-energy X-ray absorptiometry, anthropometry, total body potassium

INTRODUCTION

All clinically applicable methods for determining body composition are based on indirect measurements. Therefore, the assumptions used to derive each technique's predictive equation may, in fact, not be valid if applied to patients whose physiologies differ from the reference population (1). For example, total body water measurements assume a constant hydration of fat-free mass (FFM) of 72–74%. The total body potassium (TBK) counting method assumes sex-specific constants for the concentration of potassium in FFM of ≈68.1 mmol K^+/kg FFM in men and ≈64.2 mmol K^+/kg FFM in women (2, 3). Densitometry measurements assume that the density of the FFM is constant at 1.1 kg/L (2). Finally, whereas dual-energy X-ray absorptiometry (DXA) is theoretically free of assumptions about the above constants (4), controversy exists regarding the role of hydration and its effect on the attenuation of photons of different energy levels (5).

Because normal ranges for body composition have traditionally been developed by using well-defined, homogeneous, healthy populations, it is not surprising that questions have been raised about the applicability of these assumptions to other patient populations, particularly those with chronic diseases. The numerous assumptions required for indirect measurement of body composition may not take into account the variations in bone density, fatness, state of hydration, or potassium distribution that occur in disease states. Two previous reports addressed this issue, one in an elderly population (6) and one in malnourished patients with the acquired immunodeficiency syndrome (7). In both of these reports, assumptions of constant hydration or density of the FFM used for body-composition analysis were found to be inaccurate.

A similar situation may exist in patients undergoing chronic dialytic therapy. These patients usually have renal osteodystrophy, which changes their bone mineral density (8, 9). In addition, there is considerable difficulty differentiating between body water and body cell mass in these patients. It is well-recognized among nephrologists that the determination of euvolemia or "dry weight" in these patients is fraught with difficulty; hence, the state of hydration is in question. These patients have changes in hydration and alterations in bone mass that may affect the assumptions on which many body-composition models are based.

The purpose of this study was to compare five methods of estimating fat and/or FFM in stable peritoneal dialysis patients and then to compare these results with those of matched normal laboratory control subjects. The five modalities used were as follows: bioelectrical impedance analysis (BIA), TBK, DXA, and two anthropometric equations that are based on different measurements.

[1] From the Section of Nephrology, Sol Goldman Renal Therapy Center, Lenox Hill Hospital, New York; Baumritter Kidney Center, Albert Einstein College of Medicine, Bronx, New York; and the Body Composition Unit, St Luke's–Roosevelt Hospital Center, Columbia University, New York.

[2] Supported by a Council Grant from the National Kidney Foundation of New York/New Jersey.

[3] Address reprint requests to MV DeVita, Nephrology Section, Lenox Hill Hospital, 100 East 77th Street, New York, NY 10021.

Received May 11, 1995.

Accepted for publication April 25, 1996.

SUBJECTS AND METHODS

Peritoneal dialysis patients were recruited from the Sol Goldman Renal Therapy Center at Lenox Hill Hospital, New York, and the Baumritter Kidney Center at Albert Einstein College of Medicine, Bronx, NY. All patients were stable with no hospitalizations or episodes of peritonitis within 1 mo of study. Thirty subjects (18 males, 12 females) were studied. Nineteen patients were treated with continuous ambulatory peritoneal dialysis and 11 were treated with automated peritoneal dialysis for an average of 21.1 ± 3.2 mo (range: 1–56 mo). All body-composition studies for a given patient were done within the same day at the St Luke's–Roosevelt Hospital Body Composition Unit. The study was approved by the Institutional Review Boards of Lenox Hill Hospital and Montefiore Medical Center. Each subject gave informed consent.

In addition, body-composition data from 29 healthy, nonuremic control subjects studied by using identical techniques and devices were chosen from a large existing pool of control data obtained previously in the Body Composition Unit. The subjects were matched with the peritoneal dialysis patients for age, race, sex, height, weight, and body mass index.

Patients arrived for the studies in the fasting state having emptied their abdomen of the peritoneal dialysate fluid at 0800 on the morning of the studies. Height and weight were obtained with a precision of 0.5 cm and 0.2 kg, respectively. As detailed below, each patient underwent in random order BIA, DXA, TBK, and anthropometric measurement by both the techniques of Durnin and Womersley (10) and those of Steinkamp et al (11). Blood chemistry data (Chem 20; Ektachem, Johnson & Johnson Clinical Diagnostic Systems Inc, Rochester, NY) were obtained within 1 wk of body-composition analysis. To measure dialysis adequacy kinetic modeling studies were done within the month of testing at the Sol Goldman Renal Therapy Center and at the Baumritter Kidney Center (12). One patient was excluded because anthropometric measurements could not be done. Two patients refused to undergo TBK measurements.

Dual-energy X-ray absorptiometry

A Lunar model DPX absorptiometer (Lunar DPA software 3.6; Madison, WI) was used for this measurement, with a precision (CV) in the range of 3–4% for fat (13). The method uses X-rays of two distinct energy levels that are attenuated by fat and FFM to different extents. The relative attenuations of the two X-ray energies by the intervening fat and FFM are recorded and equations supplied by the manufacturer are used to estimate the relative proportions of fat and FFM (13).

Total body potassium

TBK was determined by using a whole-body ^{40}K scintillation counter with anthropometric correction generated by a generic ^{42}K calibration (14). The precision of these measurements ranges from 4.7% to 5.4% (14). This measurement provides an estimate for the body cell mass, which comprises a major portion of the FFM (15). The radioactive isotope ^{40}K exists as a constant proportion of the total potassium, thereby acting as a naturally occurring tracer. TBK was determined and expressed in moles of potassium. The FFM was then estimated by using the Forbes constant, which estimates males to have 68.1 mmol K^+/kg FFM and females to have 64.2 mmol K^+/kg FFM (16). Fat mass was estimated as the difference between body weight and FFM. Fat was then calculated as a percentage of body weight (2).

Bioelectrical impedance analysis

Determination of resistance and reactance was made in a standard fashion by using an RJL instrument (model 101; RJL Systems, Mt Clemens, MI). The precision of this technique is reproducible to 0.5% for the measurement of resistance and 1% for fat. BIA applies the concept that measured impedance to an electrical current can be correlated with body density and that subsequently, body density can be correlated with fat mass. Electrical conduction is related to the water and electrolyte distribution in the body because current is not conducted through fat (17). This device introduces an imperceptible alternating electrical current (800 μA at 50 kHz) via distal electrodes attached to the dorsal surfaces of the ipsilateral hand and foot; a voltage drop is detected by electrodes placed proximally on the same hand and foot. Impedance, that is, resistance and reactance, were obtained.

Once impedance was determined, correlation equations were used to determine body density. We applied empirical equations developed by Segal et al (18), which are based on underwater weighing for determination of body density. Segal et al used the formula of Goldman and Buskirk (19) to calculate the estimated body density from resistance values. The Siri (20) equation was then used to estimate percentage of fat from body density: percentage of fat = $[(4.95/\text{density}) - 4.5] \times 100$. Therefore, percentage of fat was calculated by using the density term obtained from BIA.

Anthropometry according to Durnin and Womersley

The anthropometric measurements of Durnin and Womersley (10) were used to predict body density with logarithmic transformation of the sum of four skinfold thicknesses: triceps, biceps, subscapula, and iliac crest. The equations are specific for age and sex (10). The percentage of body fat was then calculated from the body density by using Siri's equation (20). The precision of this method is ≈3.5% for percentage of body fat (10). Skinfold-thickness measurements were taken by two skilled examiners using standard techniques with Lange skinfold calipers (Cambridge Scientific Instruments, Cambridge, MD).

Anthropometry according to Steinkamp et al

Height, weight, seven circumferences, two limb lengths, five diameters, and four skinfold thicknesses were used in this method, which applies different equations according to age, sex, and race to estimate body fat. The SEE of body fat was 2.0–3.8 kg (11). Measurements were taken by two skilled examiners using standard techniques as described previously (11).

Kinetic modeling

Kt/V is a standardized term that estimates the amount of dialysis a patient receives weekly. It is used to assess adequate dialysis. Kt/V expresses a virtual volume of urea cleared during a dialysis treatment normalized to the volume of urea distributed in total body water (21). Therefore, the Kt/V term is a dimensionless ratio representing fractional urea clearance, where K is clearance, t is time, and V is volume. This measurement is based on a 24-h collection of both drained dialysate and urine, and a single serum sample as described by Keshaviah et al (12).

Statistics

All data are expressed as the mean ± SEM. Histogram plots were examined to see whether any distributions varied from an apparently normal distribution. A Shapiro-Wilks test for normality of data distribution was run for each variable (22). No significant departures from normality were noted. The primary comparative analysis of percentage of fat was by analysis of variance (ANOVA) with the body-composition measurement technique as the within-subject factor. Sex and population group (peritoneal dialysis or control) were designated as between-subject factors ($5 \times 2 \times 2$ ANOVA). Post hoc tests were by paired (for comparison of differences between techniques within groups) and independent sample t tests (for comparison of differences between groups) with the Bonferroni correction (23). Pearson product-moment correlations were used for establishing the strength of the relation between results of body-composition techniques. A Bland-Altman plot for agreement between methods was applied to strengthen correlations when appropriate (24).

RESULTS

The clinical characteristics and baseline laboratory data of the peritoneal dialysis patients and laboratory control subjects are listed in **Table 1**. As shown in Table 1, good matching was accomplished for age, weight, height, and body mass index. The dialysis patients were well dialyzed as evidenced by a mean blood urea nitrogen concentration of 22.3 ± 1.3 mmol/L, a serum creatinine concentration of 1122.7 ± 79.6 μmol/L, and a Kt/V of 2.0 ± 0.5 (range: 1.4–3.2). A Kt/V ≥ 1.8 is considered to be acceptable for peritoneal dialysis (12).

The mean percentage of body fat by sex and condition is shown in **Table 2**. The ANOVA showed a highly significant effect of technique ($P < 0.0001$) on the results of body fat determination. There was no significant effect of condition (peritoneal dialysis or control) on body fat measurement but there was a significant effect of sex, with women having a higher percentage of fat ($P < 0.0001$). There were no significant interaction terms.

TABLE 1
Clinical characteristics and baseline laboratory data[1]

Clinical characteristics	Peritoneal dialysis patients (n = 18M, 12F)	Control subjects (n = 18M, 11F)
Age (y)	45.4 ± 2.5	45.1 ± 2.5
Weight (kg)	77 ± 3.1	77.3 ± 3.2
Height (cm)	169.5 ± 2.3	170.6 ± 1.7
BMI (kg/m^2)	26.7 ± 0.9	26.5 ± 0.9
Blood urea nitrogen (mmol/L)	22.3 ± 1.32	ND
Serum creatinine (μmol/L)	1122.7 ± 79.6	ND
Kt/V[2]	2.9 ± 0.9	ND

[1] $\bar{x}$ ± SEM. ND, not determined. Groups were not significantly different for any characteristics.
[2] Fractional urea clearance.

In men, results for body fat by all techniques were found to differ significantly from each other for the within-subject analysis of body-composition techniques after the Bonferroni correction ($P < 0.005$), except for BIA with DXA and anthropometry according to Durnin and Womersley, and anthropometry according to Steinkamp et al with TBK. In women the only techniques that were found to not differ were DXA with anthropometry according to Durnin and Womersley and according to Steinkamp et al. Consequently, percentage fat values that were highly significantly different between most techniques were determined. This effect was independent of whether the subject was a control subject or peritoneal dialysis patient. This variation between techniques was reported previously (25). Our results, which show that peritoneal dialysis patients had the same variations between techniques as did laboratory control subjects, are consistent with these previous findings in normal subjects.

Because there was no significant effect of condition (peritoneal dialysis compared with control) on percentage of body fat, correlation matrixes for the comparisons between techniques were developed that combined the control and peritoneal dialysis patient data, as shown in **Table 3**. All techniques were shown to correlate significantly with one another ($P < 0.01$ or better for men and $P < 0.001$ or better for women). Because DXA and BIA showed unexpectedly high correlation, a Bland-Altman plot showing the degree of agreement between these two modalities is shown in **Figure 1**.

DISCUSSION

Our experience indicates that the standard body-composition measurement techniques we applied can be used in stable peritoneal dialysis patients. However, significant variations in percentage fat values result when different measurement techniques are used. In male peritoneal dialysis patients percentage of fat ranged from 19.6 ± 1.6% by BIA to 37.7 ± 2.5% by TBK. Female peritoneal dialysis patients were fatter with a range of from 32.0 ± 1.6% by BIA to 51.8 ± 2.9% by TBK. Data analysis revealed that although highly significant differences in percentage fat values can be expected when different body-composition measurement techniques are used, the observed variability in techniques is independent of whether the population studied consists of normal control subjects or peritoneal dialysis patients. That is, the peritoneal dialysis population studied did not differ in body-composition characteristics from the matched normal laboratory control subjects.

Our finding of variability between techniques is not new. Lukaski (2) suggested that the variations in measurements among techniques are related to systematic errors introduced by assumptions regarding compartment models, measurement techniques, and chemical constants. Jensen et al (25), in their work comparing DXA with other methods of body-composition assessment, also explain the differences they found in absolute values of FFM as being most likely due to variations in the methods, and to the different body compartments measured, rather than to problems with the techniques themselves. Furthermore, Pierson et al (26) developed intermethod equations to compare the absolute values of fat mass and FFM determined by eight different methods. Their work allows for interpretation and translation of values in the group studied.

TABLE 2
Body-composition analysis by five different techniques in peritoneal dialysis (PD) patients and control subjects[1]

	Men[2]		Women[3,4]	
	Peritoneal dialysis patients (n = 18)	Control subjects (n = 18)	Peritoneal dialysis patients (n = 12)	Control subjects (n = 11)
	% body fat			
Bioelectrical impedance analysis	19.6 ± 1.6	19.1 ± 1.9	32 ± 1.6	31.5 ± 1.3
Dual-energy X-ray absorptiometry	24.9 ± 2.6	21.9 ± 2.0	37.8 ± 2.7	37 ± 2.7
Anthropometry				
According to Durnin and Womersley (10)	22.9 ± 2.1	21.1 ± 1.4	36.1 ± 2.4	34.9 ± 2.4
According to Steinkamp et al (11)	32.9 ± 1.8	30.5 ± 1.6	39.2 ± 1.8	38.5 ± 2.5
Total-body potassium counting	37.7 ± 2.5	28.5 ± 1.9	51.8 ± 2.9	44.2 ± 3.0

[1] $\bar{x}$ ± SEM. Modalities were significantly different, $P < 0.0001$ (two-way ANOVA). There was no significant difference between peritoneal dialysis patients and control subjects.

[2] All techniques were significantly different from each other for men, $P < 0.05$, except bioelectrical impedance analysis and dual-energy X-ray absorptiometry, and the anthropometric method of Steinkamp et al and total-body potassium counting.

[3] Women had a significantly greater percentage body fat than men, $P < 0.0001$.

[4] All techniques were significantly different from each other for women, $P < 0.05$, except for dual-energy X-ray absorptiometry and the two anthropometric techniques.

The ability to obtain such equations would be supported by our finding that a high correlation exists between techniques despite the fact that they yield significantly different absolute values.

Notable in our study was the finding that measurement of TBK produced the lowest estimate of FFM or highest estimate of percentage body fat. Because the calculation of FFM is based on an assumption of sex-specific constants for the potassium concentration (68.1 mmol K^+/kg FFM in men, 64.2 mmol K^+/kg FFM in women) of FFM (2, 3) it is possible that these potassium constants may be invalid in peritoneal dialysis patients. Similar concerns regarding the use of these constants were reported by Royall et al (27) in the assessment of body composition in Crohn disease patients and by Wang et al (7) in acquired immunodeficiency syndrome patients. Reductions in cellular potassium concentrations have been reported by several authors (28–30), although these alterations in potassium content may have been related more to coexisting malnutrition. The assumptions on which TBK measurements are based to estimate FFM need to be evaluated in the dialysis population, in whom alterations in the biochemical or structural composition of muscle may exist. Body composition methods that evaluate body cell mass, such as total body water and extracellular water determination, could corroborate these findings.

The high correlation seen between the two anthropometric techniques, that of Durnin and Womersley and of Steinkamp et al, is not surprising given the similarity of the measurements. In contrast, given the differences in measurement parameters between BIA and DXA, it would not have been readily apparent that these techniques would correlate well. DXA estimates fat from a sum of regional maps of the differential attenuations of two photons of different energies, whereas BIA estimates fat from a prediction of density derived from measurements of electrical impedance. The correlation between DXA and BIA estimates of fat and the similarity in results between our peritoneal dialysis patients and control subjects, suggest that DXA and BIA measurements are concordant for fatness in a population of stable peritoneal dialysis patients.

Use of DXA for assessing fat mass is supported by the studies of Wang et al (31) and Jensen et al (25). Further support is provided by Pritchard et al (32) who showed that two different densitometers (Hologic QDR 1000W and Lunar DPX) assess percentage of fat with greater precision than does underwater weighing. Horber et al (33) reported that DXA can assess changes in total body water with resultant changes of FFM determination in patients studied before and after hemodialysis. In addition, the absolute DXA-measured fat mass may not vary with these changes in FFM; however, if fat mass is

TABLE 3
Correlation matrix for percentage body fat by body-composition techniques with peritoneal dialysis patients and control subjects grouped together by sex[1]

Body-composition measurement techniques	Men[2] BIA	DXA	DUR	STK	Women[3] BIA	DXA	DUR	STK
DXA	0.67				0.89			
DUR	0.49	0.67			0.77	0.84		
STK	0.68	0.63	0.79		0.73	0.81	0.86	
TBK	0.43	0.65	0.54	0.64	0.83	0.80	0.71	0.67

[1] BIA, bioelectrical impedance analysis; DXA, dual-energy X-ray absorptiometry; DUR, anthropometry according to Durnin and Womersley (10); STK, anthropometry according to Steinkamp et al (11); TBK, total-body potassium counting.

[2] $P < 0.01$.

[3] $P < 0.001$.

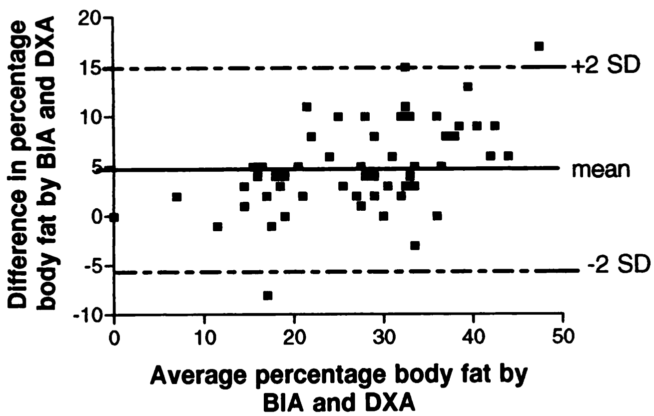

FIGURE 1. Bland-Altman plot showing difference (BIA − DXA) versus mean for percentage of fat. BIA, bioelectrical impedance analysis; DXA, dual-energy X-ray absorptiometry

subtracted from total body weight, the percentage of fat will be different. Going et al (34) also noted that DXA can detect small changes in body composition in the soft tissue related to changes in hydration status. Finally, Tothill and Avenell (35) noted that variations in body thickness may impose errors in the assessment of fat by DXA. In fact, Roubenoff et al (5) cautions against considering fat determination by DXA a "gold standard," stating that "DEXA, by measuring in essence three compartments—bone, bone-free lean, and fat—is not free of the assumption of uniform hydration." Despite important concerns raised by Roubenoff, in our view the theoretical lack of dependency on assumptions of chemical constants make DXA well suited for use in dialysis patients.

However, DXA cannot be easily used to monitor patients in an outpatient environment; it is largely restricted to use in a well-equipped body-composition laboratory. In contrast, BIA is simple to use, reliable, and readily used in a clinical setting. The ability to use this measurement technique in most clinical situations has been documented in several studies (36, 37) and it was accepted as a body-composition measurement technique in the most recent National Health and Nutrition Examination Survey (38).

The presence of overhydration and fluctuations in fluid status have caused concern regarding the use of BIA in dialysis patients. Because fat offers resistance to the applied current, and expansion of the extracellular fluid space reduces the measured resistance, hydration of tissues may result in an apparent increase in FFM and decrease in fat mass. This mechanism likely accounts for the observed reduction in resistance noted in hemodialysis patients before dialysis, with a subsequent increase in resistance after dialysis as the extracellular fluid is decreased (39–41). In studies conducted by Schmidt et al (42) and Kurtin et al (43) neither the fluid status of the patient nor the presence of abdominal fluid affected the body-fat assessment obtained when BIA was used. Our data extend these earlier observations by confirming that in stable, well-dialyzed peritoneal dialysis patients, the BIA-derived assessment of fat mass correlates highly with values obtained with DXA and with values obtained in control subjects. Finally, applicability of BIA in monitoring longitudinal changes in body composition has been studied (44–46). Considering the ease with which BIA measurements are obtained and the lack of dependence on operator interpretation, BIA is an acceptable technique for use in a clinical setting.

However, this general acceptance must be tempered by some concerns related to the use of BIA as an assessment of fat mass and FFM. Forbes et al (47) raised questions about the applicability of the basic equation used with BIA to assess changes over months or years. Furthermore, the National Institutes of Health (48) in a recently published consensus statement noted that although BIA can predict total body water, the accuracy of any subsequent estimation of fat depends on the population studied and the applicability of the prediction equation in that population. It is important to remember that BIA measurements are linked to estimates of body fat through statistical association rather than on the basis of any established biophysical principle. Clearly, more work needs to be done.

Interest in determination of fat mass and FFM has heightened in nephrologists because methods are needed to accurately assess adequacy of dialysis and nutritional status. Because differences between techniques and their results exist, the same technique should be used to follow a patient over time. These data indicate that the techniques we describe, which have been well calibrated to assess body fat in a normal population, may be used in stable peritoneal dialysis patients. Fat and FFM can be measured by using the same technique; however, results will not be comparable if different techniques are used.

REFERENCES

1. Jensen MD. Research techniques for body composition assessment. J Am Diet Assoc 1992;92:454–60.
2. Lukaski HC. Methods for the assessment of human body composition: traditional and new. Am J Clin Nutr 1987;46:537–56.
3. Forbes GB, Gallup J, Hursch JB. Estimation of total body fat from ^{40}K content. Science 1961;133:101–2.
4. Mazess RB, Peppler WW, Gibbons M. Total body composition by dual-photon (^{153}Gd) absorptiometry. Am J Clin Nutr 1984;40:834–9.
5. Roubenoff R, Kehayias JJ, Dawson-Hughes B, Heymsfield SB. Use of dual-energy x-ray absorptiometry in body-composition studies: not yet a "gold standard". Am J Clin Nutr 1993;58:589–91.
6. Baumgartner RN, Heymsfield SB, Lichtman S, Wang J, Pierson RN Jr. Body composition in elderly people: effect of criterion estimates on predictive equations. Am J Clin Nutr 1991;53:1345–53.
7. Wang J, Kotler DP, Russell M, et al. Body-fat measurement in patients with acquired immunodeficiency syndrome: which method should be used? Am J Clin Nutr 1992;56:963–7.
8. DeVita MV, Rasenas LL, Bansal M, et al. Assessment of renal osteodystrophy in hemodialysis patients. Medicine 1992;71:284–90.
9. Gabay C, Ruedin P, Slosman D, Bonjour JP, Leski M, Rizzoli R. Bone mineral density in patients with end-stage renal failure. Am J Nephrol 1993;13:115–23.
10. Durnin LV, Womersley J. Body fat assessed from total body density and its estimation from skinfold thickness. Br J Nutr 1974;32:77–97.
11. Steinkamp RC, Cohen NL, Siri WB, Sargent W, Walsh HE. Measurement of body fat and related factors in normals—II. J Chron Dis 1965;18:1292–307.
12. Keshaviah PR, Nolph KD, Prowant B, et al. Defining adequacy of CAPD with urea kinetics. Adv Perit Dial 1990;6:173–7.
13. Russell-Aulet M, Wang J, Thornton J, Pierson RN Jr. Comparison of dual-photon absorptiometry systems for total-body bone and soft tissue measurements: dual-energy x-rays versus Gadolinium 153. J Bone Miner Res 1991;6:411–5.
14. Pierson RN Jr, Wang J, Thornton C, Van Itallie TB, Colt WD. Body

potassium by 4-Pi counting: an anthropometric correction. Am J Physiol 1982;246:F234–9.
15. Roubenoff R, Kehayias JJ. The meaning and measurement of lean body mass. Nutr Rev 1991;49:163–75.
16. Forbes GB. Human body composition: growth, aging, nutrition and activities. New York: Springer-Verlag, 1987.
17. Lukaski HC, Johnson PE, Bolonchuck WW, Lykken GI. Assessment of fat-free mass using bioelectrical impedance measurements of the human body. Am J Clin Nutr 1985;41:810–7.
18. Segal KR, Gutin B, Presta E, Wang J, Van Itallie TB. Estimation of human body composition by electrical impedance methods: a comparative study. J Appl Physiol 1985;58:1565–71.
19. Goldman RF, Buskirk ER. Body volume measurement by underwater weighing: description of a method. In: Brozek J, Henschel A, eds. Techniques for measuring body composition. Washington, DC: National Academy of Sciences, 1961:79–98.
20. Siri WE. Body composition from fluid spaces and density: analysis of methods. In: Brozek J, Henschel A, eds. Techniques for measuring body composition. Washington, DC: National Academy of Sciences, 1961:223–44.
21. Ponferreda LP, Van Stone JC. Peritoneal dialysis kinetics. Adv Ren Replace Ther 1995;2:341–8.
22. Marija J. Shapiro-Wilks test. SPSS for Windows base system user's guide. Release 6.0. Chicago: Norviss SPSS Inc, 1993.
23. Wallenstein S, Zucker CI, Fleiss JL. Some statistical methods useful in circulation research. Circ Res 1980;47:1–9.
24. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;2:307–10.
25. Jensen MD, Kanaley JA, Roust LR, et al. Assessment of body composition with use of dual-energy x-ray absorptiometry: evaluation and comparison with other methods. Mayo Clin Proc 1993;68:867–73.
26. Pierson RN Jr, Wang J, Heymsfield SB, et al. Measuring body fat: calibrating the rulers. Intermethod comparisons in 389 normal Caucasian subjects. Am J Physiol 1991;261:E103–8.
27. Royall D, Greenberg GR, Allard JP, Baker JP, Harrison JE, Jeejeebhoy KN. Critical assessment of body-composition measurements in malnourished subjects with Crohn's disease: the role of bioelectric impedance analysis. Am J Clin Nutr 1994;59:325–30.
28. Rettori V, Gral T, Massry SG, Villamil MF. Exchangeable potassium content and distribution in normal subjects and uraemic patients on chronic hemodialysis. Clin Sci 1972;42:673–84.
29. De Strihou CVY. Potassium homeostasis in renal failure. Kidney Int 1977;11:491–504.
30. Mitch WE, Wilcox CS. Disorders of body fluids, sodium and potassium in chronic renal failure. Am J Med 1982;72:536–50.
31. Wang J, Russell M, Mazariegos M, et al. Body fat by dual photon absorptiometry: comparisons with traditional methods in Asians, Blacks and Caucasians. Am J Hum Biol 1992;4:501–10.
32. Pritchard JE, Nowson CA, Strauss BJ, Carlson JS, Kaymakci B, Wark JD. Evaluation of dual energy X-ray absorptiometry as a method of measurement of body fat. Eur J Clin Nutr 1993;47:216–28.
33. Horber FF, Thomi F, Casez JP, Fonteille J, Jaeger PH. Impact of hydration status on body composition as measured by dual energy X-ray absorptiometry in normal volunteers and patients on haemodialysis. Br J Radiol 1992;65:895–900.
34. Going SB, Massett MP, Hall C, et al. Detection of small changes in body composition by dual-energy x-ray absorptiometry. Am J Clin Nutr 1993;57:845–50.
35. Tothill P, Avenell A. Errors in dual-energy X-ray absorptiometry of the lumbar spine owing to fat distribution and soft tissue thickness during weight change. Br J Radiol 1994;67:71–5.
36. Segal KR, Van Loan M, Fitzgerald PI, Hodgdon JA, Van Itallie TB. Lean body mass estimation by bioelectrical impedance analysis: a four-site cross-validation study. Am J Clin Nutr 1988;47:7–14.
37. de Fijter CWH, de Fijter MM, Oe LP, Donker AJM, de Vries PMJM. The impact of hydration status on the assessment of lean body mass by body electrical impedance in dialysis patients. Adv Perit Dial 1993;9:101–4.
38. Woteki CE, Briefel RR, Kuczmarski R. Contributions of the National Center for Health Statistics. Am J Clin Nutr 1988;47:320–8.
39. de Lorenzo A, Barra PFA, Sasso GF, Battistini NC, Deurenberg P. Body impedance measurements during dialysis. Eur J Clin Nutr 1991;45:231–5.
40. Ljungqvist O, Hedenborg G, Jacobson SH, et al. Whole body impedance measurements reflect total body water changes. A study in hemodialysis patients. Int J Clin Monit Comput 1990;7:163–9.
41. Zabetakis PM, Gleim GW, Vitting KE, Gardenswartz MH, Agrawal M, Michelis MF. Volume changes affect electrical impedance measurements of body composition. Med Sci Sports Exerc 1987;19:540(abstr).
42. Schmidt R, Dumler F, Cruz C, Lubkowski T, Kilates C. Improved nutritional follow-up of peritoneal dialysis patients with bioelectrical impedance. Adv Perit Dial 1992;8:157–9.
43. Kurtin PS, Shapiro AC, Tomita H, Raizman D. Volume status and body composition of chronic dialysis patients: utility of bioelectric impedance plethysmography. Am J Nephrol 1990;10:363–7.
44. Madore F, Wuest M, Ethier JH. Nutritional evaluation of hemodialysis patients using an impedance index. Clin Nephrol 1994;41:377–82.
45. Zabetakis PM, Stall S, Krapf R, et al. Body composition and nutritional indices in peritoneal dialysis: 2 year prospective study. Perit Dial Int 1994;14:523(abstr).
46. Chertow GM, Lowrie EG, Wilmore DG, et al. Nutritional assessment with bioelectrical impedance analysis in maintenance hemodialysis patients. J Am Soc Nephrol 1995;6:75–81.
47. Forbes GF, Simon W, Amatruda JM. Is bioimpedance a good predictor of body-composition change? Am J Clin Nutr 1992;56:4–6.
48. Bioelectrical Impedance Analysis in Body Composition Measurement. NIH Technol Assess Statement 1994;Dec 12–14:1–35.