Lean Body Mass Estimation by Creatinine Kinetics

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ABSTRACT

A new technique for estimating lean body mass (LBM) from creatinine kinetics has been developed. It is based on the principle that creatinine production is proportional to LBM and that, in the steady state, creatinine production is equal to the sum of creatinine excretion (urinary and dialytic) and metabolic degradation. This technique was applied to 17 normal subjects, 26 stable, chronic hemodialysis (HD) patients, and 71 stable, chronic peritoneal dialysis (PD) patients. In the HD group, LBM was also determined by bioimpedance in 11 patients and calculated from total body water, measured as the volume of urea distribution of a sterile urea infusion, in 15 patients. In normal subjects and in the PD group, LBM was assessed by creatinine kinetics as well as by bioimpedance, near infrared, and anthropometric techniques. In the HD patients, LBM by creatinine kinetics correlated significantly with LBM from total body water and the bioimpedance technique. There was no statistical difference between the total body water and creatinine kinetics techniques, but the bioimpedance values were systematically higher than those obtained by the kinetic technique. In the PD group and in normal volunteers, LBM values by creatinine kinetics correlated significantly with the other methods but were lower. Forty-seven percent of the HD patients and 66% of the PD patients had significantly lower LBM by creatinine kinetics than expected for their sex and age. Estimation of LBM by creatinine kinetics is proposed as a simple and convenient technique for the routine nutritional assessment of dialysis patients.

Key Words: Lean body mass, creatinine kinetics, nutritional assessment, hemodialysis, peritoneal dialysis

Moderate to severe malnutrition is widely prevalent in dialysis populations (1-8). It is important to monitor the nutritional status of dialysis patients because modifications in diet, dialysis dose, and medications may reverse detrimental trends. Recent data in both hemodialysis (9) and continuous ambulatory peritoneal dialysis (CAPD) (10) suggest a strong correlation between mortality and serum albumin. Serum albumin reflects the visceral protein stores in the body, and it takes several months of sustained malnutrition for the depletion of these stores to occur. Although the serum albumin is readily measured and is included in monthly serum chemistries in most dialysis programs, a consistent historical tracking of serum albumin values to detect depletion is not routine. In malnourished dialysis patients, in addition to visceral protein depletion, there is depletion of somatic protein, as reflected in a decreasing lean body mass (LBM). LBM measurements are not routinely performed in dialysis patients; techniques for measuring LBM are not readily available, and these techniques have not been validated in dialysis populations. There has been recent interest in noninvasive techniques such as the near infrared measurement of body fat or the bioimpedance determination of total body water and LBM. Although these techniques are potentially useful for monitoring nutrition in dialysis patients, better validation is required for dialysis patients by use of comparisons with the densitometric or total body potassium techniques. Anthropometric measurements, such as the midarm circumference and scapular skinfold thickness, have been used as part of the nutritional assessment in research studies involving dialysis patients (2,8). These measurements are simple but are dependent on the skills of the operator and may not be reliable if performed by several operators over time. Recently, Nelson et al. (11) have attempted to establish anthropometric norms for the
dialysis population on the basis of a multicenter study involving 925 patients.

Urea kinetic techniques can be used in both hemodialysis and CAPD patients to calculate the protein equivalent of the urea nitrogen appearance rate (12). This term is often incorrectly referred to as the protein catabolic rate (PCR) by the dialysis community. Because this article is addressed to the dialysis community, we will continue to use the term PCR, recognizing however that it is a misnomer. There is a good correlation between PCR and dietary record analyses of protein intake (12). Recent measurements of PCR in hemodialysis patients suggest that the PCR varies significantly from dialysis to dialysis, reflecting changes in dietary habits (13). Several consecutive measurements of PCR may be required to establish a reliable average that accurately reflects nutritional status. The LBM, on the other hand, is an integrated result of dietary protein intake and expected to be a more stable and reliable measure of nutritional status. What is required is a simple, accurate, reliable, and routine technique for measuring LBM that can become an integral part of monitoring dialysis patients. If such measurements are performed routinely, with appropriate clinical interventions, one might be able to avert the more drastic consequences of increased morbidity and mortality.

The purpose of this article is to present a simple technique that we have developed for LBM estimation, based on creatinine kinetics, that can be applied to both hemodialysis and peritoneal dialysis populations. It is based on the simple principle that the creatinine generation rate is a reflection of LBM and that, in the steady state, creatinine production by muscle metabolism is equal to the sum of creatinine excretion and metabolic degradation. This technique has been assessed in both hemodialysis and peritoneal dialysis patients, and comparisons have been made with other techniques for assessing LBM (including independent calculations of LBM from total body water determinations in hemodialysis patients and bioimpedance, near infrared, and anthropometric techniques in peritoneal dialysis patients).

MATERIALS AND METHODS

Principles of Creatinine Kinetic Estimates of LBM

The basis of the technique is that, in the steady state, creatinine production is equal to the sum of creatinine excretion and metabolic degradation. Creatinine production is, in turn, proportional to the LBM of the patient. The components of creatinine excretion include dialytic removal and urinary excretion by remnant kidney function. By measuring creatinine concentrations in urine and dialysate and recording volumes of urine and dialysate, one can quantify urinary and dialytic excretion. Mitch and colleagues (14) have shown that metabolic degradation of creatinine is proportional to body weight and to serum creatinine concentration. The sum of the metabolic degradation and excretion should, in the steady state, be equal to the rate of production. Forbes and Bruining (15) have shown, in a group of 34 normal adult and pediatric subjects, a strong correlation ($r = 0.988$) between LBM (from total body potassium measurements) and creatinine excretion (3-day urine collection). The metabolic degradation of creatinine was not included, not being significant in normal subjects. On the basis of this relationship, one can calculate the LBM corresponding to the creatinine production estimated from excretion and metabolic degradation. These relationships are summarized in Table 1.

Creatinine is produced from creatine by nonenzymatic degradation. Ninety-eight percent of total body creatine is in muscle (3 to 5 g/kg of fatfree tissue) (16). Muscle metabolism, therefore, accounts for the majority of creatinine production (1 g/18 kg of fatfree muscle tissue per day). However, it has been shown that a meat-based diet may contain appreciable amounts of creatine, and even creatinine if the meat is well cooked. It is therefore possible that some of the creatinine excreted is from dietary sources rather than muscle metabolism; however, ignoring this source of creatinine input into the body only leads to an overestimation of LBM on the basis of the assumption that all of the creatinine excreted is produced by muscle metabolism. The intent of the kinetic technique is to estimate LBM in order to detect malnutrition in dialysis patients. A low LBM by this technique would, therefore, not err in detecting malnutrition. This technique may miss a mild degree of malnutrition in patients with large dietary creatine and creatinine intakes, but it could reliably detect moderate to severe malnutrition even if dietary sources of creatinine are ignored. Further, the turnover of the creatine pool is slow (half-life, approximately 43 days) (16); therefore, the influence of large variations in the creatine intake will be damped out by the slow turnover of the body pool of creatine. The effect of dietary creatine and creatinine intake on the reliability of the creatinine kinetic technique is considered in more detail in the Discussion.

Hemodialysis Studies

Creatinine kinetic studies were performed in 26 stable chronic hemodialysis patients (13 men and 13 women) at the Regional Kidney Disease Program in Minneapolis, MN, from whom informed consent had been obtained according to the guidelines of the Human Subjects Research Committee of the Hennepin County Medical Center. Dialytic excretion was deter-
TABLE 1. Creatinine kinetics^o

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>In the steady state, production</td>
<td>= excretion + metabolic degradation (urinary + dialysate)</td>
</tr>
<tr>
<td>(mg/day)</td>
<td></td>
</tr>
<tr>
<td>Excretion (mg/day)</td>
<td>= V_u - C_u + V_d - C_d</td>
</tr>
<tr>
<td>Metabolic degradation (mg/day)</td>
<td>= 0.38 \times S_{cr} (mg/dL) \times body wt (kg) (14)</td>
</tr>
<tr>
<td>LBM (kg)</td>
<td>= (0.029 \times production) (mg/day) + 7.38 (15)</td>
</tr>
</tbody>
</table>

^o V_u, volume of urine (mL/24 h); V_d, volume of effluent dialysate (mL/24 h); C_u, creatinine concentration in urine (mg/mL); C_d, creatinine concentration in effluent dialysate (mg/mL); S_{cr}, serum creatinine (mg/dL).

In addition to the creatinine kinetic studies, LBM was assessed by the bioimpedance technique in 11 of the 26 patients with a multifrequency bioimpedance analyzer (Xitron, San Diego, CA) with electrodes placed on the right wrist and ankle for the measurement of impedance. With the resistance value at 50 KHz from these impedance measurements, total body water and LBM were calculated by use of the relationships derived by Kushner and Schoeller (17) and Segal et al. (18), respectively.

LBM was also measured independently in 15 of the 26 patients by the measurement of total body water by urea infusion. The safety of this procedure in dialysis patients is documented (19). Urea is not toxic per se at serum levels below 250 mg/dL, and the small increase in BUN (=15 mg/dL) over the baseline is not of clinical concern because of its transient nature, the increase being corrected by the next dialysis.

In 10 of the 15 patients, this measurement was performed at 60 min postdialysis, after the urea rebound had occurred. In five patients, the determination was done predialysis and the volume ultrafiltered during dialysis was subtracted from the measured value to reflect total body water in the dry state postdialysis. A sterile preparation of urea for iv use (Ureaphil®; Abbott Laboratories, Chicago, IL) was reconstituted with 5% dextrose to achieve a urea concentration of 300 mg/mL. This concentration was confirmed by laboratory determination. The amount of urea to be infused was calculated to produce an elevation of 15 mg/dL in serum urea nitrogen, on the basis of an estimate of body water from body weight. The baseline of serum urea nitrogen was measured, and the required volume of Ureaphil® solution was then infused slowly through the iv route over a period of 15 to 20 min through a 0.22-μm-pore-size disk filter. After an equilibration period of 75 to 90 min, three blood samples were drawn at 5-min intervals for urea nitrogen determinations and an average value was used. The volume of body water was calculated as the volume of urea distribution on the basis of the amount of urea infused and the measured increase in BUN concentration. The urea generation rate and PCR were calculated in these studies by the standard single-pool urea kinetic technique (20); the amount of urea generated during the equilibration period of 75 to 90 min was added to the amount infused, and the volume was determined by dividing this total amount of urea by the measured increase in BUN concentration. LBM was calculated from total body water by the use of the well-established finding that 73% of LBM is body water (21).

CAPD Studies

Informed consent was obtained from 71 patients (30 women, 41 men) maintained on CAPD, according to the guidelines of the Institutional Review Board of the University of Missouri at Columbia. Twenty-four-hour collections of dialysate effluent in urine and serum samples were analyzed for concentrations of urea nitrogen and creatinine. PCR (in grams per day) was calculated according to Randerson et al. (22) and was normalized to standard body weight to yield units of grams per kilogram per day. Standard body weight was calculated as total body water/0.58, where total body water was estimated from the Watson nomogram (23). For each patient, LBM was scored on a scale of 1 to 3 by the clinical nurse as part of a 12-parameter nursing assessment score (24). A score of 1 implied that the clinical findings suggested a low LBM; a score of 2 implied a marginal LBM; and a score of 3 implied a normal LBM.

In addition to the creatinine kinetic studies, LBM was assessed by bioimpedance (15 patients), near infrared (10 patients and 17 normal subjects), and anthropometrics (10 patients). The patients in these special studies included 8 women and 11 men; the volunteer group included 4 men and 13 women. The bioimpedance studies were performed as in the hemodialysis population with a multifrequency bioimpedance analyzer (Xitron). The near infrared
studies used a noninvasive, computerized spectrometer (Futrex, Gaithersburg, MD) to measure fat at the biceps and to calculate total body fat (25). Anthropometric measurements used the sum of four skinfolds (biceps, triceps, subscapular, and suprailliac) to determine the percentage of body weight that is fat according to the method of Lindner and Lindner (26). Statistical significance was defined as \( P < 0.05 \). The number of subjects (normal volunteers, CAPD patients, and hemodialysis patients) studied with each technique and the male-female distribution in each subgroup are summarized in Table 2.

**RESULTS**

**Hemodialysis**

Total body water (in liters) and LBM (in kilograms) determinations (mean ± SE) in the 15 hemodialysis patients are summarized in Table 3 and compared with the LBM determined from creatinine kinetics. There was no significant difference (paired t test; \( P > 0.05 \)) between the LBM estimated from creatinine kinetics and that determined from total body water. The LBM by creatinine kinetics in these 15 patients was 74 ± 5.7% of body weight in men and 64 ± 4.5% of body weight in women (mean ± SE). Normal ranges of LBM depend on age and sex. On the basis of these normal ranges, we identified in the 26 hemodialysis patients 8 men (62%) and 7 women (54%) as having extremely low LBM (less than 60% body wt in women and less than 70% body wt in men) by the creatinine kinetic approach.

There was a high degree of correlation (\( r = 0.93 \)) between the LBM calculated from creatinine kinetics and that determined from the Ureaphil\textsuperscript{a}-derived total body water (Figure 1), the creatinine kinetic values of LBM being about 7% higher. The correlation between LBM from creatinine kinetics (\( r = 0.68 \)) and the PCR is shown in Figure 2.

The correlation between LBM determined by creatinine kinetics and by the bioimpedance technique is illustrated in Figure 3. There is a high degree of correlation (\( r = 0.92 \)), the line of best fit being almost parallel to the line of identity but shifted downward by about 4.5 kg, indicating that the values determined by the creatinine technique are lower by about 4.5 kg than those determined by the bioimpedance technique.

**Peritoneal Dialysis Studies**

In the 71-patient cross-sectional assessment, LBM (mean ± SE) was 47 ± 1.8 kg in men and 40 ± 1.9 kg in women. The mean LBM as a percentage of body weight was 59% (61 ± 2% in men and 57 ± 2% in

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**TABLE 2. Subjects (normal volunteers, CAPD patients, and hemodialysis patients) studied by various techniques**

<table>
<thead>
<tr>
<th>Creatinine Kinetics</th>
<th>Bioimpedance</th>
<th>Near Infrared</th>
<th>Anthropometrics</th>
<th>Total Body Water by Urea Infusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Volunteers</td>
<td>17 (4 M, 13 F)</td>
<td>—(a)</td>
<td>17 (4 M, 13 F)</td>
<td>—</td>
</tr>
<tr>
<td>CAPD</td>
<td>71 (41 M, 30 F)</td>
<td>15 (9 M, 6 F)</td>
<td>10 (4 M, 6 F)</td>
<td>10 (5 M, 5 F)</td>
</tr>
<tr>
<td>Hemodialysis</td>
<td>26 (13 M, 13 F)</td>
<td>11 (5 M, 6 F)</td>
<td>—</td>
<td>15 (8 M, 7 F)</td>
</tr>
</tbody>
</table>

*\(a\) Dashes indicate measurements not taken.

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**TABLE 3. LBM by creatinine kinetics and urea infusion total body water in hemodialysis patients (mean ± SE)*

<table>
<thead>
<tr>
<th></th>
<th>Total Body Water (L)</th>
<th>LBM\textsubscript{bw} (kg)</th>
<th>LBM\textsubscript{tot} (kg)</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male ((N = 8))</td>
<td>40.4 ± 3.2</td>
<td>55.3 ± 4.4</td>
<td>58.3 ± 5.4</td>
<td>NS\textsuperscript{c}</td>
</tr>
<tr>
<td></td>
<td>(74.1 ± 5.7)\textsuperscript{b}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female ((N = 7))</td>
<td>25.1 ± 1.3</td>
<td>34.4 ± 1.7</td>
<td>36.9 ± 3.2</td>
<td>NS\textsuperscript{c}</td>
</tr>
<tr>
<td></td>
<td>(64.2 ± 4.5)\textsuperscript{b}</td>
<td></td>
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</tr>
</tbody>
</table>

\(a\) tbw, total body water; \(b\) creatinine. 
\(c\) Numbers in parentheses are LBM\textsubscript{bw}, as % body weight.

* Comparison between LBM\textsubscript{bw} and LBM\textsubscript{tot}. NS, not significant.
women). Of men, 73% had an LBM of less than 70% of body weight; in women, 57% had an LBM of less than 60% of body weight. Overall, 66% were below these lower limits of normal. The mean normalized PCR was 0.94 ± 0.22 g/kg per day.

The nurses estimated that there were 18, 48, and 5 patients with scores of 3, 2, and 1, respectively. The LBM by creatinine kinetics as a percentage of body weight in these three groups were (mean ± SE) 62.4 ± 3.4, 59.4 ± 1.6, and 48.9 ± 5.8, respectively. The mean LBM in Group 1 was less than the mean LBM in Group 3, being on the threshold of significance (P = 0.059). The means of LBM estimates from creatinine kinetics were not significantly different between Groups 2 and 3 (P = 0.165) and were on the threshold of significance between Groups 1 and 2 (P = 0.060).

Correlations of LBM with serum creatinine (Figure 4) and serum albumin (Figure 5) were highly significant. LBM as a percentage of body weight also correlated significantly with the clearance of urea by dialysis (r = 0.39; P < 0.0008), drain volume (r =
Figure 5. LBM by creatinine kinetics is related to serum albumin concentration in 71 CAPD patients. The linear regression line is shown.

0.35; P < 0.0025), dialysate creatinine concentration (r = 0.54; P < 0.0001), age (r = -0.29; P < 0.0126), and PCR (r = 0.34; P < 0.0039).

In the LBM measurement technique comparisons, there was a very high correlation of LBM by near infrared with LBM by bioimpedance, as shown in Figure 6. The correlation of LBM by creatinine kinetics with LBM by near infrared was also significant, but in many patients and normal volunteers, values from creatinine kinetics were lower than those from the infrared technique (Figure 7A). Figure 7B shows the correlation of LBM by creatinine kinetics with LBM by bioimpedance; Figure 7C shows the correlation of LBM by creatinine kinetics with that by the anthropometric technique. The latter two correlations were also significant, but again, many LBM values by creatinine kinetics were below those values by other techniques. Mean values by creatinine kinetics were lower than those by other techniques, and differences were significant by paired t analysis.

Figure 6. LBM by near infrared is related to LBM by bioimpedance in CAPD patients. The line shown is the identity line.
Figure 7. LBM by creatinine kinetics is related to LBM by near infrared (A), bioimpedance (B), and anthropometrics (C) in CAPD patients. The lines shown are the identity lines.
(P < 0.0112 versus bioimpedance; P < 0.0005 versus anthropometrics; P < 0.0001 versus near infrared). Differences between bioimpedance and near infrared were not significant.

The relationship between LBM and creatinine production used in the creatinine kinetic calculations was established by Forbes and Bruining (15) in a normal population of 34 adult and pediatric patients: LBM was determined by the measurement of total body potassium. In order to calibrate LBM by the bioimpedance technique to daily creatinine production in hemodialysis and CAPD patients, the linear regressions between bioimpedance LBM and daily creatinine production are plotted in Figure 8. In hemodialysis patients, this relationship is LBM = 16.1 + 0.024 × creatinine production (r = 0.92). In the CAPD population, the relationship is LBM = 23.0 + 0.021 × creatinine production (r = 0.66).

DISCUSSION

Malnutrition is widely prevalent in both hemodialysis and CAPD populations, as has been frequently reported (1–8). In this study, 47% of the hemodialysis patients and 66% of the peritoneal dialysis patients had a significantly lower LBM by creatinine kinetics than the lower limits established for normal subjects, accounting for sex and age.

In both groups, men had an average higher LBM as a percentage of body weight and the LBM correlated inversely with age. Patients assessed by nurses as definitely having a low LBM (score of 1) had a lower LBM by creatinine kinetics compared with those assessed as normal; the difference was on the threshold of significance.

The high degree of correlation between LBM from creatinine kinetics and LBM from total body water determinations in hemodialysis patients supports the validity of this simple technique for estimating LBM. There was also a very high correlation between LBM by the kinetic technique and LBM as determined by bioimpedance. However, values by the bioimpedance technique were systematically higher. In the bioimpedance technique, the impedance of body water to the passage of an electric current is measured. Both the intracellular and extracellular body water compartments contribute to the measured impedance. Because the method was established in a normal population, a certain relationship between intracellular and extracellular body water volumes is implied. Because this relationship may be perturbed in dialysis patients, the validity of the LBM calibration to impedance measurements may be questionable. For example, if there is a larger percentage of extracellular body water in dialysis patients than in normal subjects, an overestimation of LBM by the bioimpedance technique may occur, because the calibration of the technique imputes some of this fluid overload to cellular mass.

In peritoneal dialysis patients, the creatinine kinetic LBM correlated well with indices of dialysis dose (dialysis urea clearance and drain volume), other parameters affected by muscle mass (serum and dialysate creatinine concentrations), indices of nutrition (serum albumin and PCR), and inversely with age. Relative to dialysis dose, we cannot tell from these
studies whether patients with a higher LBM have an upward adjusted dialysis dose or whether patients with a larger dialysis dose have better preservation of LBM.

In terms of correlations of LBM measured by creatinine kinetics with measurements by bioimpedance, near infrared, or anthropometrics, there is no gold standard with proven accuracy in a peritoneal dialysis population. The correlation between bioimpedance and near infrared measurements was the best, with both techniques yielding higher values than creatinine kinetics. The accuracy of bioimpedance measurements of LBM has frequently and recently been challenged (27). The bioimpedance technique may overestimate LBM in dialysis patients with fluid overload, as indicated above. Also, the near infrared technique measures body fat directly and deduces LBM from this measurement on the basis of relationships between body fat and LBM established in normal subjects. In CAPD patients, the daily absorption of glucose from the dialysis fluid is associated with an increase in body fat that is most noticeable in the first 2 yr of CAPD exposure. The calibration of the near infrared technique in normal subjects with a different relationship between body fat and LBM may yield questionable results in CAPD patients. This comment also applies to the anthropometric determinations of LBM on the basis of skinfold and midarm circumference measurements. Nelson et al. (11) have performed anthropometric measurements in 925 stable dialysis patients in order to establish norms for the dialysis population. They found no difference between male hemodialysis patients (diabetic and nondiabetic) and men in the National Health and Nutrition Examination Survey (NHANES) II. However, there were significant differences from NHANES II in female, nondiabetic hemodialysis patients and in older, black, female, diabetic hemodialysis patients. Further, Pollock et al. (28) have shown that, in CAPD patients, anthropometric measurements are not sensitive enough to detect malnutrition established by total body nitrogen using neutron activation analysis.

Incomplete collections could yield low values of LBM by creatinine kinetics as compared with near infrared and bioimpedance; however, in these studies, collections were deemed to be carefully done and complete in most instances. The relationships on which calculations of LBM from body fat and total body water are based were established in normal subjects. However, many normal volunteers in our study also had lower LBM by creatinine kinetics. Perhaps the creatinine production per unit muscle mass is more variable than appreciated, and/or perhaps creatinine degradation is higher than predicted from serum creatinine with the formula used.

The concern that dietary creatinine and/or creatine might yield falsely high values for LBM by the use of creatinine kinetics was certainly not apparent in these studies relative to the comparisons with other techniques, because the creatinine kinetic values of LBM were lower than with other techniques. Significant dietary contributions to creatinine excretion would have led to an overestimation of LBM.

It is instructive to consider the effect of the dietary contribution of creatine and creatinine on the LBM calculation. Let us first consider the effect of dietary creatinine intake. According to Heymsfield et al. (29), the "average" daily American diet includes 200 g of meat, which contains 700 mg of creatine and 37 mg of creatinine. When the meat is cooked at 77°C, the creatinine content increases to 160 mg and the creatine content decreases to 570 mg. Creatine excretion (dialytic and urinary) is of the order of 1,400 to 1,750 mg/day for a 70-kg body wt. Adding a metabolic degradation value of 350 mg (based on a serum creatinine of 12 mg/dL and a body weight of 70 kg) to this, we get a total creatine production of 1,750 to 2,100 mg/day. The dietary creatinine contribution of 160 mg is therefore of the order of 8 to 9% of the total creatinine production. The technique would overestimate LBM by 8 to 9% by imputing the dietary contribution to muscle metabolism. Let us now consider the effect of creatine in the diet. The creatine pool in the body turns over slowly (half life, ~43 days), the conversion rate of creatine to creatinine being between 1.1 and 2.6% per day, depending on whether the source of creatinine is creatine or phosphocreatine. The effect of a significant change in dietary intake is therefore not manifest immediately. Crim et al. (30) studied the effect of changing from a 9-day low-creatine diet (0.23 g/day) to a 10-day high-creatine diet (10 g/day) and found a 28% increase (range, 10 to 30%) in urinary creatine excretion from 1.8 to about 2.3 g/day. In order to achieve this increase of 28%, the creatine content of the diet was changed from approximately one third of the average diet to 14 times the creatine content of the average diet—a change of 4,200%. Because dietary changes of this magnitude are uncommon, we expect that even a twofold to threefold change in dietary creatine intake will not result in large errors.

As stated earlier, if dietary contributions had introduced a major error in the calculation, we would have noted systematic overestimates of LBM. Our actual experience was to the contrary. What is really of importance for longitudinal evaluations of a patient's nutritional status is to look at systematic variations in the creatine production rate over time, some "noise" in the measurement being expected. In a sense, this is analogous to the estimation of protein intake from the urea nitrogen appearance rate. Even though we do not measure nitrogen losses in feces, sweat, semen, exhaled air, etc., we are still able to
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deduce protein intake from dialytic and urinary losses of urea nitrogen. Similarly, we can calibrate LBM to creatinine production to yield reasonable estimates of nutritional status.

Perhaps more important than the validity of the absolute value of LBM in any patient may be the ability to monitor trends in an individual patient by any single technique. In both the hemodialysis and CAPD populations, there was a strong correlation between the biotimpedance LBM and daily creatinine production. The intercepts and slopes of these regressions were different between normal subjects, hemodialysis patients, and CAPD patients; this is probably related to differences in the calibration of the bioimpedance technique in these different populations rather than to major differences in the relationship between creatinine production and actual LBM. Changes in daily creatinine production over time in a given patient should reliably indicate trends of change in LBM. Because many centers routinely collect 24-h urine and dialysate samples for evaluating clearances and PCR in CAPD patients, it would be very easy to also monitor daily creatinine production as an index of long-term nutrition.

The creatinine kinetic approach to LBM estimation is simple and easy to apply routinely. It appears to correlate well with other techniques for estimating LBM that are not as readily accessible. The method is applicable to both CAPD and hemodialysis patients and suggests that malnutrition is prevalent in both populations. The PCR, by virtue of its variability, may not reliably indicate malnutrition in dialysis patients, especially if the patient has an unusually high protein intake on the day of study. The LBM may be a more reliable indicator of long-term nutritional status and needs to be considered in routine assessments of nutrition.

REFERENCES