We tested the agreement between classifications of the weight status of patients on peritoneal dialysis (PD) by body mass index (BMI) and by body fat (BF) content (BF/W, where W = actual weight), when BF was computed as BF = W – V / 0.73 from the Sahlgrenska, Watson, or Hume anthropometric formulas estimating body water (V) in 933 patients on PD and 7,737 outpatients without hydration disorders. We used currently accepted cut-off values for classifying subjects as underweight, normal-weight, overweight, and obese by BMI and BF/W. We obtained these values: BMI: men on PD (n = 555), 25.5 ± 4.3; men with normal renal function [NRF (n = 5,906)], 27.7 ± 5.1; women on PD (n = 378), 25.9 ± 6.1; women with NRF (n = 1,831), 28.3 ± 6.5; BF_{Sahlgrenska}/W—men on PD, 0.238 ± 0.063; men with NRF, 0.274 ± 0.052; women on PD, 0.342 ± 0.089; women with NRF, 0.366 ± 0.075. We obtained these regressions:

Women on PD
\[ \text{BMI} = 12.0832 + 38.9550 \left( \frac{\text{BF}_{\text{Sahlgrenska}}}{W} \right) - 92.9252 \left( \frac{\text{BF}_{\text{Sahlgrenska}}}{W} \right)^2 + 254.0675 \left( \frac{\text{BF}_{\text{Sahlgrenska}}}{W} \right)^3, \quad r^2 = 0.917; \]

Men on PD
\[ \text{BMI} = 19.4729 - 29.1310 \left( \frac{\text{BF}_{\text{Sahlgrenska}}}{W} \right) + 213.7045 \left( \frac{\text{BF}_{\text{Sahlgrenska}}}{W} \right)^2, \quad r^2 = 0.888. \]

From those regressions, the BMI value corresponding to the BF_{Sahlgrenska}/W cut-off for underweight was similar to the National Institutes of Health (NIH) BMI cut-off for underweight. The BMI value corresponding to the BF_{Sahlgrenska}/W cut-off for obesity was substantially lower than the NIH BMI cut-off for obesity. The \( \kappa \) ratios of the classifications of weight status by BMI and BF_{Sahlgrenska}/W varied between 0.142 and 0.304 (poor agreement), with more than 50% of the subjects classified in a more obese weight category by BF_{Sahlgrenska}/W than by BMI. Classification of the subjects by BMI and by BF_{Sahlgrenska}/W in quintiles or quartiles led to much higher \( \kappa \) ratios, particularly in women. The results were similar in subjects with NRF and with the use of the Watson and Hume formulas to estimate BF. The use of arbitrary cut-off values of BMI or anthropometric BF/W to classify PD patients or patients without edematous states as underweight, normal-weight, overweight, or obese leads to substantial disagreement between the two classifications. Classification of weight status by BMI or BF/W in quintiles or quartiles improves substantially the agreement between the two classifications and should be preferred.

Key words
Body composition, underweight, normal-weight, overweight, obesity, body mass index, body fat content

Introduction
The weight status of peritoneal dialysis (PD) patients is usually classified by body mass index (BMI) (1). The BMI is a surrogate value for body fat (BF) content (2). Discrepancies between the evaluations of degree of obesity by BMI and by BF content may result from the fact that BMI accounts only for height and weight, and not for other important determinants of body composition such as sex, age, ethnicity, skeletal frame, physical activity, nutrition status, and catabolic (particularly neurologic) illness. Inevitably, classification of weight status by BMI misclassifies a fraction of a population (3). Classification of weight status by BF content may avoid the errors of the height–weight indices (3–5). Body fat is determined in PD patients by skin-fold thickness, dual energy X-ray

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absorptiometry, bioelectrical impedance analysis, and counting of body potassium or nitrogen (6).

In PD patients with normal hydration, estimates of body water ($V$) can be used to estimate fat-free mass and BF (7). Several anthropometric formulas are available for estimating $V$ in PD patients. Estimates of BF calculated by anthropometric formulas were in close agreement with the corresponding estimates obtained using reference methods of analyzing body composition for the average subjects of studies that determined $V$ by a tracer dilution technique in PD (7,8).

In the present study, we compared classifications of weight status in PD patients by BMI and by BF content obtained from three anthropometric formulas. We addressed these questions:

Are cut-off values for weight status by BMI and by BF content from anthropometric formulas comparable?

Can misclassification be avoided by modifying the cut-offs?

**Patients and methods**

We compared classifications of weight status by BMI and by BF content in two groups of patients: one group had normal renal function (NRF) and one group was on PD. The group with NRF consisted of patients followed in the primary care clinics of the New Mexico VA Health Care System. From the last clinic visit of each patient, we extracted age, height, weight, and clinical diagnosis. Only subjects with major edematous states (congestive heart failure, renal failure, cirrhosis of the liver, and nephrotic syndrome) were excluded. The PD population consisted of patients analyzed at their first clearance study.

Weight status by BMI is classified as follows (9):

- BMI < 18.5, underweight;
- 18.5 ≤ BMI < 25, normal-weight;
- 25 ≤ BMI < 30, overweight;
- BMI ≥ 30, obese.

Weight status by the ratio BF/W, where W is actual body weight, is classified as follows (5):

- BF/W < 0.20 (women) or BF/W < 0.12 (men), underweight;
- 0.20 ≤ BF/W < 0.30 (women) or 0.12 ≤ BF/W < 0.20 (men), normal-weight;
- 0.30 ≤ BF/W < 0.33 (women) or 0.20 ≤ BF/W < 0.25 (men), overweight;
- BF/W ≥ 0.33 (women) or BF/W ≥ 0.25 (men), obese.

The anthropometric estimate of BF, assuming normal hydration, is calculated as follows (7):

$$BF = W - V / 0.73$$

Continuous variables are reported as mean ± standard deviation. Patients with NRF and those on PD were compared by the two-tailed non-paired Student $t$-test. The relationship between BF/W and BMI was examined by regression analysis, with BF/W as the x-axis. The classifications of weight status by BMI and by BF/W were compared using the Cohen $\kappa$ ratio (13). A $\kappa$ ratio < 0.40 indicates low probability of agreement; a $\kappa$ ratio between 0.40 and <0.75 indicates reasonable probability of agreement; and a $\kappa$ ratio ≥0.75 indicates a high probability of agreement beyond chance.

**Results**

Table I shows the pertinent characteristics of the two populations studied. We analyzed a total of 7,737 subjects with NRF and 933 patients on PD. Men with NRF were older than those on PD ($p < 0.001$). For both women and men, patients without renal failure were taller, heavier, and more obese than those on PD and had a lower incidence of diabetes ($p < 0.001$ for all comparisons).

Figure 1 shows the best-fit regression of BMI on BF/W in men on PD (upper panel) and in women on PD (lower panel). Both regressions were curvilinear. From those regressions, the BMI values corresponding to the BF/W cut-offs for underweight (0.20 in women and 0.12 in men) were 18.1 and 19.0 respectively. The BMI values corresponding to the BF/W cut-offs for obesity (0.33 in women and 0.25 in men) were 23.9 and 25.5 respectively. Regressions in subjects with NRF produced very similar findings.

The $\kappa$ ratios of the classifications of subjects as underweight, normal-weight, overweight, or obese by BMI and BF/Sahlgrenska/W using the cut-off values shown in the Methods section were between 0.142 in men with NRF and 0.304 in women on PD, indicating poor degree of agreement. Classification by BF/W tended to classify subjects in a more obese weight category. Among 933 subjects on PD, 15 (1.6%) were classified in a more obese category by BMI; 411 (44.1%) were classified in the same weight category by BMI and BF/Watson/W; and 507 (54.3%) were classified in a more obese weight category by BF/W. Corresponding values for the 7,737 subjects with NRF were 15 (0.2%), 3,350 (43.3%), and 4,372 (56.5%) respectively. The $\kappa$ ratios between BMI and BF/W varied between 0.068 and 0.292, and the $\kappa$ ratios between BMI and BF/Hume/W varied between 0.300 and 0.498.
Comparisons of the weight classifications by BMI and BF/W were repeated using quintiles and quartiles instead of arbitrary cut-offs. For classification by quintiles, the $\kappa$ ratios were in the range 0.752 – 0.797 in women (indicating high probability of agreement) and 0.526 – 0.579 in men (indicating a reasonable probability of agreement). Similar results were obtained from the comparison of weight classification by quartiles.

**Discussion**

Body composition is determined by several factors other than height and weight. Omission of the effects of those additional factors can cause the misclassification of subjects when classification of weight status uses the arbitrary cut-off values of the surrogates for BF content (3–5). Estimates of BF content from the Sahlgrenska, Watson, and Hume formulas (and two other formulas) produced no systematic deviations from estimates obtained by reference methods in subjects with average body composition (8). That observation permitted the present study. The results were very similar in subjects with NRF and those on PD.

The main findings of the present study are that, regardless of the anthropometric formula used, classifications of weight status by BMI and by anthropometric BF/W differ widely when arbitrary cut-off values are used (although the Hume formulas, which do not include age terms, produced slightly better $\kappa$ ratios). The BMI values corresponding to the BF/W cut-offs for obesity were substantially lower than the
NIH BMI cut-off of 30 (9). Consequently, more than 50% of subjects were classified in a more obese category by BF/W than by BMI. But when weight categories were classified not by arbitrary cut-off values, but by quintiles or quartiles, the agreement of the BMI and BF/W classifications improved dramatically. Findings were similar in PD patients and in outpatients with NRF (chosen because they had no hydration problems) and were not substantially changed by the use of various anthropometric formulas to estimate BF/W.

Potential systematic errors of weight status classification by BMI and by anthropometric BF/W should be recognized. Overhydration will result in a subject being classified as more obese either by BMI or by anthropometric BF/W. The overestimation of BMI is strictly a linear function of the fraction of body weight represented by overhydration. For example, a 10% increase in weight from volume gain translates to a 10% increase in BMI. Overestimation of the degree of obesity by anthropometric BF/W in overhydration is more complex. It depends on sex, age, height, and weight in addition to fluid gain. For example, in a 50-year-old man with a height of 170 cm and a dry weight of 70 kg, BF/W overestimates the BF/W at dry weight by 14.4% for a fluid gain of 7 kg (10% of dry weight) and by 36.6% for a fluid gain of 21 kg (30% of dry weight). Corresponding values for a woman of the same age, height, and dry weight are 11.2% and 28.7% respectively. Obesity may cause false increases of anthropometric V and fat-free mass to appear falsely lower than actual BF/W values (7,10,14). However, those problems become significant only in advanced obesity and do not affect the classification of weight status by BF/W.

Conclusion
In PD patients, classifications of weight status that use arbitrary cut-off values of BMI and anthropometric BF/W are subject to great disagreement—disagreement that is also found in subjects without hydration disorders. Given the fact that BMI accounts for only a fraction of the determinants of body composition, certain patients are probably misclassified by BMI cut-off values. Classification by quartiles or quintiles is preferable, because it leads to less disagreement.

Acknowledgment
This work was supported by the New Mexico VA Health Care System.

References
12 Hume R, Weyers E. Relationship between total body


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