

# Estimation of Creatinine Clearance in Morbidly Obese Patients

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## Abstract and Introduction

### Abstract

**Purpose:** Estimates of creatinine clearance ( $CL_{Cr}$ ) based on equations and various body-size descriptors were compared with 24-hour measured  $CL_{Cr}$  values in morbidly obese patients.

**Methods:** Patients age 18-75 years with a body mass index (BMI) of  $\geq 40$  kg/m<sup>2</sup> with stable serum creatinine values were enrolled. Covariates known to contribute to alteration in  $CL_{Cr}$  were used to exclude patients. Twenty-four-hour urine collection was performed to measure  $CL_{Cr}$ . Bioelectric impedance analysis was used to estimate fat-free weight (FFW). Glomerular filtration rate was estimated using the four-variable Modification of Diet in Renal Disease (MDRD4) equation.  $CL_{Cr}$  was estimated using the Cockcroft-Gault and Salazar-Corcoran methods using total body weight (TBW). Body-size descriptors, such as ideal body weight (IBW), adjusted body weight (ABW), and lean body weight (LBW), and FFW were substituted in the Cockcroft-Gault equation to generate additional estimates of  $CL_{Cr}$ .

**Results:** Fifty-four patients (mean  $\pm$  S.D. age,  $48.4 \pm 12.9$  years; TBW,  $142.3 \pm 41.7$  kg; BMI,  $50.5 \pm 12.6$  kg/m<sup>2</sup>) completed the study. All three equations were biased in their estimation of  $CL_{Cr}$ . Use of MDRD4 and IBW in the Cockcroft-Gault equation underestimated  $CL_{Cr}$ , while the Salazar-Corcoran equation and use of TBW or ABW in the Cockcroft-Gault equation overestimated this value. Substitution of fat-free weight or LBW in the Cockcroft-Gault equation provided unbiased estimates of  $CL_{Cr}$ .

**Conclusion:** An LBW estimate, based on TBW and BMI, incorporated into the Cockcroft-Gault equation provided an unbiased, relatively precise, accurate, and clinically practical estimate of 24-hour measured  $CL_{Cr}$  in morbidly obese patients.

### Introduction

Accurate estimation of renal function is particularly problematic in morbidly obese patients. We compared estimates of creatinine clearance ( $CL_{Cr}$ ) that used various body-size descriptors to determine which method most closely approximated the actual measured 24-hour  $CL_{Cr}$  in morbidly obese patients.

## Background

The prevalence of obesity in the United States has reached epidemic proportions. According to the National Health and Nutrition Examination Survey III, approximately half of the U.S. population over age 20 years are overweight or obese.<sup>[1]</sup> Obese patients are classified into three groups based on a body mass index (BMI) of 30.0-34.9, 35.0-39.9, and  $\geq 40.0$  kg/m<sup>2</sup>.<sup>[2]</sup> This last group is often referred to as morbidly obese and constitutes 5% of the U.S. population.<sup>[1]</sup> Many studies have demonstrated that obesity predisposes patients to an increased risk for diseases such as hypertension, cardiovascular disease, and type 2 diabetes mellitus.<sup>[3]</sup> While the guidelines on evaluation and treatment of obesity address the effect of obesity on blood pressure control, glucose regulation, and cardiovascular health, more research is necessary to better understand its effect on renal function.<sup>[3]</sup> Chagnac and colleagues<sup>[4]</sup> found that overweight patients have an increased glomerular filtration rate (GFR) and increased renal plasma flow. Renal hyperfiltration occurs through renal vasodilation in a compensatory response to overcome the increased tubular reabsorption of sodium. However, vasodilation of afferent arterioles increases the hydrostatic pressure in the glomerulus, which can lead to hypertrophy over time and renal disease, even in patients without diabetes.<sup>[3]</sup> In addition, hyperlipidemia, leptin, and adipocyte-derived hormones contribute to the development of glomerular

sclerosis. Thus, the results of these studies indicate that obesity independently affects the filtering capacity of the kidneys over time.<sup>[3]</sup>

As a result, a better assessment of renal function and dosage adjustment of drugs eliminated by the kidneys is needed in obese patients. The GFR is considered to be the best indicator of the filtering capacity of the kidneys and overall measure of renal function.<sup>[5]</sup> The most commonly used equations to estimate GFR are based on serum creatinine concentration (SCr). These equations provide practical and inexpensive methods for estimating GFR through the surrogate measure of  $CL_{Cr}$ . However, their accuracy and precision are affected by factors such as age, muscle mass, diet, and proximal tubule secretion of creatinine.<sup>[5]</sup> Most of the equations currently published for estimating  $CL_{Cr}$  have not been validated for use with obese patients. The exception is the Salazar-Corcoran<sup>[6]</sup> equation, developed using an obese rat model and then validated using data from obese patients from a study conducted by Dionne and colleagues.<sup>[7]</sup> Several studies have evaluated the accuracy and precision of currently published equations that estimate GFR in obese patients.<sup>[8-10]</sup> All methods produced  $CL_{Cr}$  estimates that significantly differed from the measured  $CL_{Cr}$ . On the other hand, two retrospective studies found the Salazar-Corcoran method to be the only unbiased and most precise equation for estimating  $CL_{Cr}$  in obese patients.<sup>[9,10]</sup> Aside from the Salazar-Corcoran method, there are no other valid equations for estimating  $CL_{Cr}$  in obese patients.

Recently, the Modification of Diet in Renal Disease (MDRD) Study Group developed a four-variable equation (MDRD4) to estimate the GFR using SCr, age, sex, and race.<sup>[11]</sup> The equation was evaluated in 1628 patients with a mean total body weight (TBW) of 79.6 kg. The MDRD4 equation does not include weight as a variable and thus avoids potential weight-related bias when used for obese patients. However, the equation has not been studied extensively with obese patients or patients with normal SCr values. In addition, the estimated GFR is expressed in milliliters per minute per  $1.73\text{ m}^2$ , necessitating the use of body surface area (BSA) equations to obtain GFR estimates in milliliters per minute. Since BSA equations have never been validated in obese patients, their use may contribute to biased results for this population.<sup>[12]</sup> Currently, the National Kidney Disease Education Program (NKDEP) advocates the use of the MDRD4 equation only for staging chronic kidney disease.<sup>[5]</sup> It does not recommend basing adjustments in drug dosing on  $CL_{Cr}$  estimates using the MDRD4 equation.

One of the most commonly used methods for estimating GFR is through the surrogate  $CL_{Cr}$  using the Cockcroft-Gault equation.<sup>[13]</sup> All Food and Drug Administration (FDA)-approved package inserts provide dosing adjustments based on  $CL_{Cr}$  estimated using the Cockcroft-Gault equation.<sup>[5]</sup> In addition, most pharmacokinetic studies in patients with chronic kidney disease have relied on the Cockcroft-Gault equation to stratify patients' disease severity. As a result, the Cockcroft-Gault equation has become a gold standard for estimating  $CL_{Cr}$  to adjust dosing regimens. However,  $CL_{Cr}$  is known to increase in a linear manner with lean body weight (LBW), and surrogates of this parameter have evolved to improve estimated  $CL_{Cr}$  by the Cockcroft-Gault method. Ideal body weight (IBW) as a substitute for LBW underestimates  $CL_{Cr}$  when using the Cockcroft-Gault equation.<sup>[14]</sup> This underestimation is expected, as obese patients have a greater total LBW than do normal-weight individuals of equal height, which is not accounted for by IBW equations. Adjusted body weight (ABW), which includes an adjustment factor of 0.3 ( $ABW_{0.3}$ ) or 0.4 ( $ABW_{0.4}$ ) to represent gain in LBW between TBW and IBW, was developed as a possible solution.<sup>[8,15]</sup> However, the validity of this approach in morbidly obese individuals has not been evaluated.

Han and colleagues<sup>[16]</sup> suggested that the use of LBW provides a more accurate estimate of  $CL_{Cr}$ . They used an LBW equation derived by Janmahasatian and colleagues<sup>[17]</sup> to reanalyze renal clearance data from another study that included normal-weight and obese patients. The results revealed that drug clearance for patients with different heights and weights is the same after adjusting for body composition. Consequently, the authors proposed that pharmacokinetic studies should use LBW to relate clearance and body composition.<sup>[17]</sup> They also recommended estimating LBW using derived equations or standard methods such as dual-energy x-ray absorptiometry (DXA) or bioelectric impedance analysis (BIA).

The Cockcroft-Gault equation is the most widely used clinical method for estimating  $CL_{Cr}$  to adjust drug dosages. We conducted a prospective study to evaluate whether the use of different body-size descriptors could improve  $CL_{Cr}$  estimates using the Cockcroft-Gault equation. We hypothesized that use of fat-free weight (FFW) estimated using BIA in the Cockcroft-Gault equation would provide better estimates of  $CL_{Cr}$ . In addition, we compared the Cockcroft-Gault using TBW, IBW, FFW, and LBW with the MDRD4 and Salazar-Corcoran equations for estimating  $CL_{Cr}$  in obese patients. We enrolled only morbidly obese patients (BMI of  $\geq 40.0$  kg/m<sup>2</sup>), since this population has been consistently underrepresented in previous trials.

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## Methods

We conducted a single-center, cross-sectional study at the University of New Mexico Hospital (UNMH). This study was approved by the human research review committee and the scientific review panel of the UNMH's General Clinical Research Center. Written informed consent was obtained from participants before the study began. Morbidly obese patients (BMI of  $\geq 40.0$  kg/m<sup>2</sup>) age 18-75 years admitted to UNMH between August 1, 2005, and May 31, 2007, were screened for study inclusion. Patients with any of the following criteria were excluded from the study: > 20% change in SCr (from hospital admission to day of study initiation), admission to an intensive care unit, inability to walk unassisted, diagnosis of congestive heart failure, treatment with any known nephrotoxic agents (e.g., amphotericin B, cyclosporine, tenofovir), or treatment with cimetidine, trimethoprim-sulfamethoxazole, corticosteroids, or probenecid. In addition, pregnant or lactating women and patients with liver disease (Child-Pugh category B or C) were excluded.

### Measurement of $CL_{Cr}$

To measure  $CL_{Cr}$ , we performed a timed 24-hour urine collection. Patients were instructed to void before the urine collection was started. Urine specimens were stored on ice until the analysis was performed. Analysis was performed within 4 hours after the end of collection to avoid additional conversion of creatine to creatinine. SCr values were obtained from the UNMH clinical database or by performing venous blood sampling at some point during the day of the urine collection if not performed as a routine standard of care. Urinary and serum creatinine concentrations were measured by an automated method using a Vitros 5,1 FS analyzer (Ortho Clinical Diagnostic, Rochester, NY) using an enzymatic method (Tricore Reference Laboratories, Albuquerque, NM).<sup>[18]</sup> The interday and intraday coefficients of variation for this assay were < 2%. Measured  $CL_{Cr}$  was calculated using the standard formula as outlined in the appendix. Adequate 24-hour urine collection was verified by comparing the measured 24-hour urinary creatinine output (urinary creatinine concentration x urine volume) with the expected urinary creatinine output of approximately 15 mg/kg of IBW per day for women and 20 mg/kg of IBW per day for men. In addition,  $CL_{Cr}$  was estimated in milliliters per minute for each patient with the Cockcroft-Gault, Salazar-Corcoran, and MDRD4 equations. In addition, we substituted six body-size descriptors (TBW, IBW, ABW<sub>0.3</sub>, ABW<sub>0.4</sub>, FFW, and LBW) into the Cockcroft-Gault equation to reflect various clinical approaches.

### Determination of FFW Using BIA

We determined FFW and total body water using BIA according to the National Institutes of Health Technology Assessment Conference Statement.<sup>[19]</sup> All patients were required to fast for at least four hours before BIA measurement. A portable impedance Quantum II analyzer (RJL Systems, Detroit, MI) using the standard tetrapolar method was utilized. Briefly, two distal current-introducing electrodes were placed on the dorsal surfaces of the hand and foot. In addition, two voltage-sensing electrodes were applied at the wrist and ankle. Measurements were made with the patients in supine position for at least 15 minutes and application of a 50-kHz alternating current. Patients' arms and legs were abducted at a 30-45° angle from the trunk. The resistance measurements from the impedance device were used along with height, weight, and age in a regression equation derived by Gray and colleagues<sup>[20]</sup> to calculate FFW.

### Statistical Analyses

One-way analysis of variance was used to compare measured and calculated  $CL_{Cr}$  and GFR values; post hoc comparisons were performed with Tukey's test. Ordinary least-squares linear regression was used to compare slopes, intercepts, and correlation coefficients for equation-estimated  $CL_{Cr}$  or GFR with 24-hour measured  $CL_{Cr}$ . The influence of leverage points was assessed with natural logarithmic transformation and by Cook's D. Bias was defined as the mean difference between the estimated  $CL_{Cr}$  for each equation and the measured  $CL_{Cr}$ , while precision was defined as the root mean-squared error. The 95% confidence intervals were constructed around the slopes, y-intercepts, and bias. Bland-Altman plots were generated to describe bias relative to the mean of the measured and estimated  $CL_{Cr}$  values. Equation accuracy was defined as the percentage of patients with estimated  $CL_{Cr}$  values that were  $\leq 30\%$  and  $\leq 50\%$  of the measured  $CL_{Cr}$ .<sup>[21]</sup> All analyses were performed using STATA IC, version 10 (Stata Corp., College Station, TX).

## Results

A total of 58 patients were recruited and completed study procedures; however, the urine samples of 4 patients were lost, who were thus excluded. summarizes the demographics of the 54 study patients, the majority of whom were women (63%). The race and ethnicity of the study population were consistent with demographic features of New Mexico. Forty-six patients (85%) had an SCr concentration of  $\leq 1.0$  mg/dL, and only 2 (4%) had an SCr concentration over 1.4 mg/dL. Seventeen patients (31%) had a BMI of  $\geq 50$  kg/m<sup>2</sup>. The various body-size descriptors provided weight measures that were 34.3-57.3% lower than the TBW. The mean  $\pm$  S.D. values of these body-size descriptors were as follows: 60.8  $\pm$  11.2 kg for IBW, 85.3  $\pm$  17.4 kg for ABW<sub>0.3</sub>, 93.4  $\pm$  20.6 kg for ABW<sub>0.4</sub>, 72.1  $\pm$  19.6 kg for FFW, and 66.8  $\pm$  14.8 kg for LBW.

**Table 1. Patient Characteristics**

Variable	Women (n = 34)	Men (n = 20)	Total (n = 54)
Age (yr)			
Mean $\pm$ S.D.	51.3 $\pm$ 12.5	43.6 $\pm$ 12.4	48.4 $\pm$ 12.9
Median (range)	52.0 (29.0-74.0)	47.5 (21.0-65.0)	48.5 (21.0-74.0)
Race/ethnicity (no. [%])			
Non-Hispanic white	18 (53)	9 (45)	27 (50)
Hispanic	14 (41)	9 (45)	23 (43)
Native American	1 (3)	2 (10)	3 (6)
Black	1 (3)	0	1 (2)
Serum creatinine concentration (mg/dL)			
Mean $\pm$ S.D.	0.8 $\pm$ 0.3	0.9 $\pm$ 0.2	0.8 $\pm$ 0.3
Median (range)	0.7 (0.5-1.8)	0.8 (0.6-1.3)	0.8 (0.5-1.8)
Total body weight (kg)			
Mean $\pm$ S.D.	132.7 $\pm$ 35.0	158.7 $\pm$ 47.6	142.3 $\pm$ 41.7
Median (range)	123.8 (99.0-256.0)	147.0 (112.0-320.0)	128.2 (99.0-320.0)
Body mass index (kg/m <sup>2</sup> )			
Mean $\pm$ S.D.	50.6 $\pm$ 12.0	50.3 $\pm$ 13.9	50.5 $\pm$ 12.6

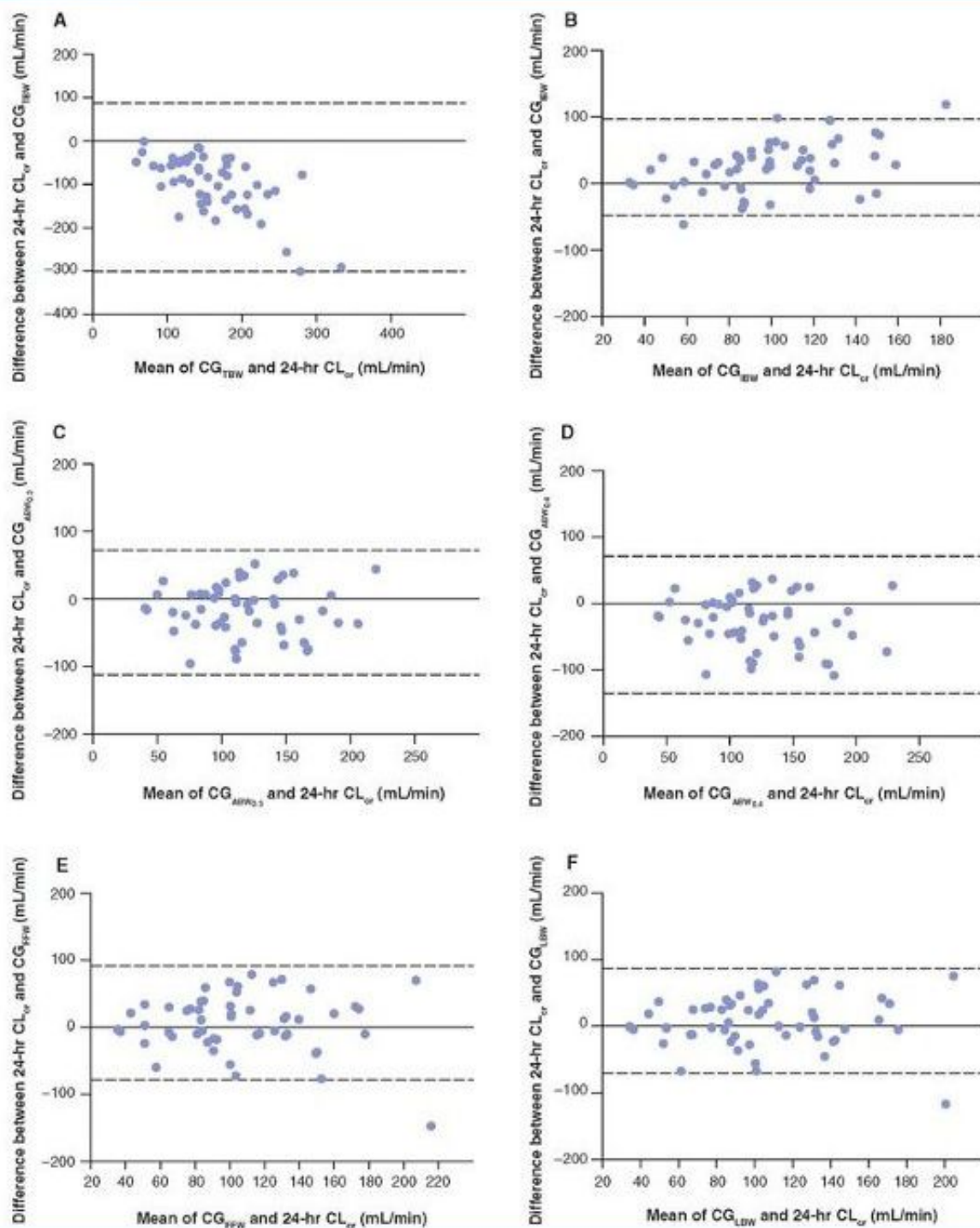
Median (range)	45.6 (40.1-88.6)	45.2 (40.2-95.6)	45.6 (40.1-95.6)
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The mean  $\pm$  S.D. measured  $CL_{Cr}$  was  $109.5 \pm 44.4$  mL/min. The mean, bias, precision, and accuracy of the various estimation methods are summarized in . Only the Cockcroft-Gault<sub>FFW</sub> and Cockcroft-Gault<sub>LBW</sub> provided estimates of  $CL_{Cr}$  that were not significantly different ( $p > 0.05$ ) from measured values. In addition, both of these equations provided unbiased estimates of measured  $CL_{Cr}$  (Figure 1). As expected, use of Cockcroft-Gault<sub>TBW</sub> grossly overestimated measured  $CL_{Cr}$ . The Cockcroft-Gault<sub>ABW<sub>0.3</sub></sub>, Cockcroft-Gault<sub>ABW<sub>0.4</sub></sub>, and Salazar-Corcoran equations all overestimated measured  $CL_{Cr}$  values in the study patients. In contrast, the Cockcroft-Gault<sub>IBW</sub> and the MDRD4 equations underestimated measured  $CL_{Cr}$  values. The Cockcroft-Gault<sub>LBW</sub> equation was the most precise, and the MDRD4 equation was the least. The Cockcroft-Gault<sub>FFW</sub> and Cockcroft-Gault<sub>LBW</sub> equations yielded the highest accuracy (55-61%), in yielding values that were within 30% of the measured  $CL_{Cr}$ .

**Table 2. Performance of Various Methods of Estimating Creatinine Clearance ( $CL_{Cr}$ ) or Glomerular Filtration Rate (GFR)<sup>a</sup>**

Method	Mean $\pm$ S.D. or GFR $CL_{Cr}$ (mL/min)	Mean Bias (mL/min) (95% CI)	Precision		Accuracy (% Patients)	
			$r^2$	RMSE	$\leq 30\%$ of Measured $CL_{Cr}$	$\leq 50\%$ of Measured $CL_{Cr}$
Measured $CL_{Cr}$	$109.5 \pm 44.4$					
Cockcroft-Gault <sub>TBW</sub>	$216.9 \pm 113.1$	-107.4 (-133.2, -81.5)	0.272	37.83	12.9	29.6
Cockcroft-Gault <sub>IBW</sub>	$85.3 \pm 29.4$	24.3 (14.6, 33.9)	0.326	36.41	48.1	88.9
Cockcroft-Gault <sub>ABW<sub>0.3</sub></sub>	$129.4 \pm 55.3$	-19.8 (-32.1, -7.6)	0.339	36.07	53.7	75.9
Cockcroft-Gault <sub>ABW<sub>0.4</sub></sub>	$141.9 \pm 63.1$	-32.3 (-46.2, -18.5)	0.326	36.40	51.8	66.7
Cockcroft-Gault <sub>FFW</sub>	$102.7 \pm 48.1$	6.8 (-4.5, 18.2)	0.324	36.46	61.1	83.3
Cockcroft-Gault <sub>LBW</sub>	$101.5 \pm 43.3$	8.1 (-2.6, 18.7)	0.352	35.68	55.6	87.0
Salazar-corcoran	$155.2 \pm 65.1$	-45.7 (-59.9, -31.5)	0.326	36.40	46.2	55.6
MDRD4	$96.3 \pm 29.4$	13.3 (2.3, 24.3)	0.172	40.36	51.9	87.0

<sup>a</sup>CI = confidence interval; RMSE = root mean-squared error; TBW = total body weight; IBW = ideal body weight;  $ABW_{0.3}$  = adjusted body weight (ABW) using 0.3 to represent gain in lean body weight (LBW) between TBW and IBW;  $ABW_{0.4}$  = ABW using 0.4 to represent gain in LBW between TBW and IBW; FFW = fat-free weight; MDRD4 = four-variable Modification of Diet in Renal Disease equation.



Source: Am J Health-Syst Pharm © 2009 American Society of Health-System Pharmacists

Figure 1.

Bland-Altman plots of measured 24-hour creatinine clearance (CL<sub>cr</sub>) versus CL<sub>cr</sub> estimated by the Cockcroft-Gault (CG) method using total body weight (TBW) (A), ideal body weight (IBW) (B), adjusted body weight with constant 0.3 (ABW<sub>0.3</sub>) (C), ABW with constant 0.4 (ABW<sub>0.4</sub>) (D), fat-free weight (FFW) (E), and lean body weight (LBW) (F). The dashed line represents the interval mean of 1.96 S.D. to -1.96 S.D.



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## Discussion

The common use of the Cockcroft-Gault equation suggests that it will remain the method of choice for drug dosing in patients with renal impairment. In contrast, the MDRD4 equation is likely to remain a clinical tool for staging chronic kidney disease. The reliance of the Cockcroft-Gault equation on weight as a key variable has reduced its accuracy in patients with obesity. Improved approaches to body-size description using LBW provide an opportunity to improve this equation.<sup>[12]</sup>

However, measuring actual LBW is not simple. In contrast, the IBW equations, which serve as a surrogate of LBW, are simple to use but were not derived by rigorous scientific means.<sup>[14]</sup> As a result, IBW equations have been consistently documented to underestimate  $CL_{Cr}$  in obese patients.<sup>[7]</sup> Correction of this IBW bias has been attempted through the use of ABW for specific drugs and has improved estimates of  $CL_{Cr}$ .<sup>[8]</sup> However, the generalizability of this approach is unknown, and the most appropriate correction factor for estimation of ABW arouses further debate. Given these constraints, improved estimates of LBW remain the most meaningful method of generating a universal body-size descriptor to aid in drug dosing. Most importantly, development of a simple method of estimating LBW increases its chances of clinical applicability.

According to Green and Duffull,<sup>[12]</sup> LBW appears to be the most useful approach to estimate clearance and volume of distribution for most drugs. Duffull and colleagues<sup>[22]</sup> developed a patient normalized weight (PNWT) equation for patients with a BMI of  $> 30 \text{ kg/m}^2$ . This equation provided better predictions of gentamicin clearance than the use of TBW -- a most relevant finding, given that gentamicin clearance approximates GFR. Unfortunately, the equations for PNWT are not suitable for patients with a BMI of  $> 52 \text{ kg/m}^2$ . In the current study, PNWT was not used because that BMI applied to 16 (30%) of our patients. Recognizing this limitation, Janmahasatian et al.<sup>[17]</sup> used a two-stage semimechanistic model to derive a LBW function based on height, TBW, and sex. The model used a rigorous scientific approach to estimate LBW using DXA and BIA methods in two separate populations. The resultant LBW estimate was used in the current study.

We demonstrated that the MDRD4 and Salazar-Corcoran equations provided biased estimates of  $CL_{Cr}$  without improvement of precision or accuracy of estimates relative to measured values. Similarly, body-size descriptors such as TBW, IBW, and ABW were biased and inaccurate when applied in the Cockcroft-Gault equation. In contrast, FFW estimates using BIA and LBW estimates using the outlined approach were unbiased. These body-size descriptors also resulted in more precise and accurate estimates of  $CL_{Cr}$ . The current study validates the findings of Janmahasatian and colleagues,<sup>[23]</sup> which indicated that LBW is the body-size descriptor that best predicts GFR measured by inulin clearance.

The growing obesity epidemic presents continued challenges for pharmacists who are faced with drug dosing considerations. An estimated 1 in 20 Americans is morbidly obese, and this number is expected to more than double by 2015.<sup>[24]</sup> The potential adverse events that can result from underdosing or overdosing patients with obesity have not been well characterized. However, emerging data suggest that worse pharmacologic outcomes occur among obese patients relative to normal weight patients. Standardization of body-size description is a critical point that must be addressed in future pharmacokinetic studies in order to improve dosing recommendations in this population.<sup>[12]</sup> Surrogates of LBW have predated the Cockcroft-Gault equation, and most of these values used in pharmacy practice (e.g., IBW, ABW) are likely applied without a scientific basis. The results of the current study validate the concept that LBW estimation through FFW using BIA provides improved estimates of  $CL_{Cr}$  in obesity. However, the availability and feasibility of BIA as a routine clinical tool remain unlikely. Consequently, estimation of LBW through improved equations such as those proposed by Janmahasatian and colleagues<sup>[17]</sup> seems the most viable approach.

The current study is limited in that alternative estimation methods of  $CL_{Cr}$  were not studied. An additional 10 equations could have been pursued as viable options. In addition, the current data set could have been used to derive a new equation to estimate  $CL_{Cr}$  in this extremely morbidly obese population (31% of patients with a BMI of  $> 50$

kg/m<sup>2</sup>). Both options were considered but dismissed as futile approaches to changing pharmacy practice, given engrained curricula, FDA guidelines, and NKDEP recommendations.<sup>[5]</sup> The current study also included a limited sample of patients with chronic kidney disease and did not include a healthy outpatient population. We utilized stringent criteria to eliminate variables known to influence CL<sub>cr</sub>. However, potential unmeasured confounding variables associated with hospitalized patients may have inadvertently affected our results. Finally, GFR was represented by 24-hour measured CL<sub>cr</sub> instead of more accurate measures (e.g., inulin or <sup>125</sup>I-sodium iothalamate clearance). Despite these limitations, the current study included a population that has not been evaluated systematically using CL<sub>cr</sub> and GFR equations.

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## Conclusion

An LBW estimate, based on TBW and BMI, incorporated into the Cockcroft-Gault equation provided an unbiased, relatively precise, accurate, and clinically practical estimate of 24-hour measured CL<sub>cr</sub> in morbidly obese patients.

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## Appendix: Equations and Body Weights Used in Study

### Measured 24-hour CL<sub>cr</sub> (mL/min):

$$\frac{U_{cr} V_u}{SCr(1440 \text{ min})}, \text{ where } U_{cr} = \text{urine creatinine (in milligrams per deciliter)}, V_u = \text{urine volume (in milliliters)}, \text{ and } SCr = \text{serum creatinine (in milligrams per deciliter)}$$

### Cockcroft–Gault (mL/min)<sup>[13]</sup>:

$$\frac{(140 - \text{age}) \times \text{weight (kg)}}{SCr \times 72} \times (0.85 \text{ if female})$$

### Salazar–Corcoran (mL/min)<sup>[6]</sup>:

$$\text{Male: } \frac{(137 - \text{age}) \times ([0.285 \times TBW] + [12.1 \times \text{height in meters}]^2)}{51 \times SCr}$$

, where TBW = total body weight

$$\text{Female: } \frac{(146 - \text{age}) \times ([0.287 \times TBW] + [9.74 \times \text{height in meters}]^2)}{60 \times SCr}$$

### MDRD4 (mL/min/1.73 m<sup>2</sup>)<sup>[11]</sup>:

$$186 \times SCr^{-1.154} \times \text{age}^{-0.203} \times (0.742 \text{ if female}) \times (1.210 \text{ if black})$$

### Total body weight:

$$\text{Measured body weight}$$

### Fat-free weight<sub>male</sub>:

$$0.00139 \times (\text{height in centimeters})^2 - 0.0801 \times R + 0.187 \times TBW + 39.83$$

where R = resistance

### Fat-free weight<sub>female</sub>:



$$0.00151 \times (\text{height in centimeters})^2 - 0.0344 \times R + 0.140 \times TBW - (0.158 \times \text{age}) + 20.387$$

**Ideal body weight<sub>male</sub>:**

$$50.0 + 2.3 \times (\text{number of inches over 5 ft})$$

**Ideal body weight<sub>female</sub>:**

$$45.5 + 2.3 \times (\text{number of inches over 5 ft})$$

**Adjusted body weight:**

$$IBW + C \times (TBW - IBW), \text{ where } IBW = \text{ideal body weight,} \\ C = \text{either } 0.3 \text{ or } 0.4 \text{ (} ABW_{0.3} \text{ or } ABW_{0.4} \text{), and } ABW = \text{adjusted body weight}$$

**LBW<sub>male</sub>:**

$$0.9270 \times TBW / 6680 + 216 \times BMI, \text{ where } BMI = \text{body mass index (in kilograms per meters squared)}$$

**LBW<sub>female</sub>:**

$$0.9270 \times TBW / 8780 + 244 \times BMI$$

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