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REVIEW

# Automating and estimating glomerular filtration rate for dosing medications and staging chronic kidney disease

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**Objective:** The purpose of this paper is to serve as a review for primary care providers on the bedside methods for estimating glomerular filtration rate (GFR) for dosing and chronic kidney disease (CKD) staging and to discuss how automated health information technologies (HIT) can enhance clinical documentation of staging and reduce medication errors in patients with CKD.

**Methods:** A nonsystematic search of PubMed (through March 2013) was conducted to determine the optimal approach to estimate GFR for dosing and CKD staging and to identify examples of how automated HITs can improve health outcomes in patients with CKD. Papers known to the authors were included, as were scientific statements. Articles were chosen based on the judgment of the authors.

**Results:** Drug-dosing decisions should be based on the method used in the published studies and package labeling that have been determined to be safe, which is most often the Cockcroft–Gault formula unadjusted for body weight. Although Modification of Diet in Renal Disease is more commonly used in practice for staging, the CKD–Epidemiology Collaboration (CKD–EPI) equation is the most accurate formula for estimating the CKD staging, especially at higher GFR values. Automated HITs offer a solution to the complexity of determining which equation to use for a given clinical scenario. HITs can educate providers on which formula to use and how to apply the formula in a given clinical situation, ultimately improving appropriate medication and medical management in CKD patients.

**Conclusion:** Appropriate estimation of GFR is key to optimal health outcomes. HITs assist clinicians in both choosing the most appropriate GFR estimation formula and in applying the results of the GFR estimation in practice. Key limitations of the recommendations in this paper are the available evidence. Further studies are needed to better understand the best method for estimating GFR.

**Keywords:** laboratory automation, glomerular filtration rate, medications, dose adjustment

## Introduction

Accurate estimation of kidney function is essential for appropriate medical and medication management and to prevent medication errors. Common examples of medication errors in patients with kidney disease include: inappropriate drug dose adjustments for degree of kidney function; therapeutic omissions of renal protective agents; failure to monitor and adjust for chronic kidney disease (CKD) progression and subsequent changes to drug regimens; and avoidance of nephrotoxins. Approximately 23% of medications that need to be dose- or regimen-modified in CKD are not appropriately adjusted.[1] Additionally, 13% of the medications given to persons with CKD are contraindicated.[2] Failure to appropriately dose adjust medications for declines in kidney function significantly increases the risk of mortality by 40% and can significantly increase health

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care utilization costs.[2] For example, inappropriate dose adjustment of antithrombotics can result in minor or major bleeding events, which cost more than US$600 and US$1,500, respectively.[3] The progressive nature of kidney dysfunction warrants close vigilance to ensure that as the function declines, medications are appropriately managed.

An estimated 59% of patients with CKD are prescribed drugs that are known to be cardioprotective and/or renoprotective.[4] As even mild CKD is an independent predictor of significant cardiovascular morbidity and all-cause mortality, the timely addition of cardioprotective and renoprotective agents is imperative. There is extensive evidence that demonstrates slowing the decline of kidney function[5–10] and improvement in cardiovascular outcomes[11–12] with angiotensin-converting enzyme inhibitors and angiotensin receptor blockers. Preventable medication errors in patients with CKD are concerning because they not only contribute to the nearly $3 trillion spent annually on health care expenditures in the US, but they also lead to suboptimal health and quality-of-life outcomes. The reason for these medication errors is multifactorial and includes: inappropriate estimation of kidney function; the progressive nature of kidney function decline in CKD; lack of provider time to estimate kidney function; inadequate education on how to interpret and use the various measures for estimating kidney function; and confusion regarding the use of one equation for staging kidney disease and another equation for dosing drugs. Measuring kidney function requires measurement of inulin, iothalamate, or iohexol clearance by analytical techniques and equations not readily available to clinicians.[13]

Estimation of the glomerular filtration rate (GFR) is performed clinically through the use of an equation that can be performed at the bedside. As GFR declines, some medications require adjustments at specific GFR thresholds, and some medications do not require dose- or regimen-adjustments at all. Examples of common drugs that primary care clinicians encounter that require dose- and regimen-adjustments in CKD are presented in Table 1.

Instead of using GFR, providers often inappropriately rely on serum creatinine (SCr) measurement alone to determine kidney function. SCr provides limited information, as there is significant variability between the measured SCr and GFR between patients. Furthermore, while declines in GFR and kidney function are in the same direction, SCr is reciprocal to kidney function with increasing SCr representing a decline in function. However, due to the busy practices of primary care clinicians, kidney function is often mentally estimated via the SCr level versus the calculation of a GFR.

A recent study of 19 clinicians found that 79% rely on both GFR and SCr measurements when the GFR estimation is automatically reported by the laboratory; however, 100% rely solely on SCr as an indicator of kidney function when GFR is not automatically reported by the laboratory.[14] Some of the many factors that influence SCr include sex, age, race-related differences in muscle mass, exercise, malnutrition, diurnal variation, cirrhosis, and drugs. Even when SCr is

**Table 1** Commonly used drugs that require renal dose adjustments or are contraindicated at variable GFR thresholds[a]

| |
|---|
| Medications requiring dose adjustments |
| Acyclovir |
| Allopurinol |
| Amoxicillin |
| Amoxicillin/clavulanate |
| Ciprofloxacin |
| Dabigatran |
| Enoxaparin |
| Famotidine |
| Fluconazole |
| Gabapentin |
| Gemifloxacin |
| Glimepiride |
| Levetiracetam |
| Levofloxacin |
| Memantine |
| Metformin |
| Metronidazole |
| Penicillin g |
| Phenazopyridine |
| Piperacillin/tazobactam |
| Pregabalin |
| Ranitidine |
| Rivaroxaban |
| Sitagliptin |
| Sulfamethoxazole/trimethoprim |
| Tenofovir |
| Tramadol |
| Varenicline |
| Zoledronic acid |
| Contraindicated medications |
| Eplerenone |
| Exenatide |
| Glyburide |
| Liraglutide |
| Nitrofurantoin |
| Nonsteroidal anti-inflammatory drugs |
| Probenecid |
| Spironolactone |
| Tramadol ER |

**Notes:** [a]These medications do not require dose adjustments and are not contraindicated for all persons with CKD. Each medication requires either a dose adjustment or is contraindicated as a unique GFR value.
**Abbreviations:** GFR, glomerular filtration rate; CKD, chronic kidney disease; ER, extended release.

within the normal range, a person can have CKD. Relying on SCr alone results in the underdiagnosis of CKD, given that 25% of SCr measurements within normal limits translates to a GFR that is diagnostic for CKD.[15] For example, based on SCr alone, a patient with an SCr of 0.9 mg/dL would not be diagnosed with CKD; however, further assessment via GFR indicates stage 3 CKD. Table 2 summarizes the typical GFR values and measurement methods for CKD staging and drug dosing.

Many formulas have been developed to estimate GFR, and most rely on SCr measurements. In general, the GFR estimating equations have niches in clinical practice; however, the many formulas that can be used to estimate GFR make it challenging for providers to appropriately identify the ideal formula for a given situation. Further complicating the GFR estimation issue, laboratories, or health information technology (HIT) services may not automate GFR reporting, may use an incorrect formula, or may use a formula that has not been identified for the clinician.

The purpose of this manuscript is to serve as a review for primary care providers on the bedside methods for estimating GFR for dosing and CKD staging and to discuss how HIT can be used to automate the reporting process to enhance clinical documentation of staging and to reduce medication errors in patients with kidney disease.

## Methods

A nonsystematic search of PubMed (through March 2013) was conducted to determine the optimal approach to estimate GFR for dosing and CKD staging and to identify examples of how automated HITs can improve health outcomes in patients with CKD. Papers known to the authors were included, as were scientific statements. Articles were chosen based on the judgment of the authors. Inherent in the design of nonsystematic reviews is author bias in article selection.

## Using appropriate GFR estimation formula

Common equations for estimating GFR include: the Modification of Diet in Renal Disease (MDRD);[16] the Cockcroft–Gault (CG);[17] and the Chronic Kidney Disease Epidemiology Collaboration (CKD–EPI).[18] Although each equation has its unique niche in practice and its own set of limitations, central to all of these equations are the incorporation of corrections for age, race, weight, sex, and other factors in addition to SCr. Body surface area (BSA) is incorporated into some equations with the thought that GFR is proportional to kidney size, which is proportional to BSA.

The CG or estimated creatinine clearance equation was the first of these three equations developed; it was determined by studying predominately hospitalized adult male patients.[16] The CG equation attempts to control for age, sex, and weight; it is reported as mL/min.[16] The CG equation is often the standard equation used for calculating drug doses, since historical drug labeling contains dosing information in reference to CG. However, the CG equation underestimates GFR in the elderly and is less accurate in patients with normal kidney function.

The MDRD equation (abbreviated as "eGFR") was the second equation developed. It was developed by studying nonhospitalized persons with CKD.[17] MDRD normalizes for race, BSA, age, and sex; it is reported as mL/minute/1.73 $m^2$. MDRD is predominantly used for CKD staging in clinical practice. Several limitations of the MDRD equation have been documented. Since the MDRD equation was derived from persons with CKD, it is imprecise and underestimates GFR at higher values, yielding false positives for CKD. Furthermore,

**Table 2** Methods for assessing kidney function by GFR and staging CKD

| Formula for assessing GFR | Purpose | Interpretation by GFR[a] |
|---|---|---|
| MDRD[16] | Staging CKD | CKD stage 1: GFR >90 mL/minute/1.73 $m^2$ |
| CKD-EPI[17] | Staging CKD | CKD stage 2: GFR 60–89 mL/minute/1.73 $m^2$ |
| | | CKD stage 3: GFR 30–59 mL/minute/1.73 $m^2$ |
| | | CKD stage 4: GFR 15–29 mL/minute/1.73 $m^2$ |
| | | CKD stage 5: GFR <15 mL/minute/1.73 $m^2$ |
| Cockcroft–Gault (CG)[18] | Dose adjustment | Degree of dose adjustment varies by drug and CG-estimated GFR |
| | | Normal renal function: >80 mL/minute |
| | | Mild impairment: 50–80 mL/minute |
| | | Moderate impairment: 30–50 mL/minute |
| | | Severe impairment: <30 mL/minute |
| | | End stage renal disease: dialysis required[5] |

**Note:** [a]CKD staging also includes evidence of kidney damage, which is not included in this table.
**Abbreviations:** GFR, glomerular filtration rate; CKD, chronic kidney disease; MDRD, Modification of Diet in Renal Disease.

the MDRD equation has not been evaluated in: persons <18 years of age; persons >75 years of age; pregnant women; extremes in body size; or in races other than Caucasian and African American.[17]

CKD–EPI, the newest equation, was determined with a cross-sectional analysis of a sample of persons who were representative of the US population.[18] The CKD–EPI normalizes for race, BSA, age, and sex and is reported as mL/min/1.73 $m^2$. In clinical practice, CKD–EPI is most commonly used for CKD staging. Although the CKD–EPI is a more accurate estimation of GFR than MDRD at all values and more representative of the US population, the CKD–EPI sample population included limited elderly and minority populations.[18] To compare the MDRD or CKD–EPI values with CG, it is customary to multiply or to adjust the MDRD and CKD–EPI values (mL/minute/1.73 $m^2$) by the patient's BSA to have all equation results in the same units of measurement (mL/minute). Table 3 describes the MDRD, CG, and CKD–EPI formulas and the applicable factors in each equation.

Each equation incorporates SCr. However, in recent years, all SCr measurements in the US became standardized to prevent variations due to the assay or instrument used, which can impact the accuracy of the equations if not taken into account. Of the commonly used GFR estimation formulas, the CKD–EPI was actually developed using the standardized SCr measurements, while the MDRD equation was re-expressed for use with the standardized SCr measurements. Unfortunately, CG cannot be re-expressed, because the original blood samples used to develop the CG equation are no longer available. As a result of not being able to re-express the CG equation for standardized SCr, CG-estimated GFR results are 5%–10% higher using the standardized SCr measurements when compared to nonstandardized SCr.[19] Relying on CG-estimated GFR based on standardized SCr measurements decreases the accuracy of this GFR estimation and could lead to unintended consequences, including insufficient dose adjustments for kidney function. However, the clinical significance of this theoretical issue requires study.

## Estimating GFR for medication adjustment

Appropriately adjusting a medication dose or regimen for kidney function ensures the medication reaches safe and effective drug concentrations for the targeted indication and ultimately achieves optimal clinical outcomes. Therefore, appropriate drug dose- and regimen-adjustments are imperative to the provision of quality health care. However, the use of several estimating equations for kidney function assessment can be confusing for clinicians who need to discern which equation should be used for dosing medications.

The CG equation is the most often used formula for dose-adjusting medications based on kidney function and is endorsed by the National Kidney Foundation (NKF)[20] and the American College of Cardiology (ACC)/American Heart Association (AHA).[21] However, the NKF also recommends that – in addition to CG – the MDRD unadjusted for BSA (not multiplying MDRD by the patient's BSA) is a reasonable method for adjusting medication doses based on kidney function.[20]

It is important to discriminate that while the NKF and the ACC/AHA have more leverage regarding clinical practice issues, the US Food and Drug Administration (FDA) has less impact on clinical practice but extensive oversight on the pharmaceutical industry and drug development process. Despite some inconsistency in the national recommendations as to which formula to use for drug dose and regimen adjustments in CKD, the 1998 FDA Guidance for Industry document recommends using CG for drug labeling recommendations.[22] However, a 2010 updated draft of the 1998 FDA document incorporates reporting both CG and MDRD GFR estimates in the literature of new products,[23] but the draft has not yet been finalized. It is important to understand that most recommendations in the drug product

**Table 3** Common GFR estimation formulas

| | | |
|---|---|---|
| Cockcroft–Gault (eCrCl)[16] | ([140 – age in years] × ideal body weight in kg)(× 0.85 if female) ([SCr in mg/dL] × 72) | |
| MDRD (eGFR)[17] | 170 × (SCr in mg/day)$^{-0.999}$ × (age in years)$^{0.318}$ × (0.762 if female) × (1.18 if African American) | |
| CKD–EPI[18] | African American, female, SCr ≤0.7 | 166 × ([SCr in mg/dL]/0.7)$^{-0.329}$ × (0.993)$^{(age\ in\ years)}$ |
| | African American, female, SCr >0.7 | 166 × ([SCr in mg/dL]/0.7)$^{-1.209}$ × (0.993)$^{(age\ in\ years)}$ |
| | African American, male, SCr ≤0.9 | 163 × ([SCr in mg/dL]/0.9)$^{-0.411}$ × (0.993)$^{(age\ in\ years)}$ |
| | African American, male, SCr >0.9 | 163 × ([SCr in mg/dL]/0.9)$^{-1.209}$ × (0.993)$^{(age\ in\ years)}$ |
| | White or other, female, SCr ≤0.7 | 144 × ([SCr in mg/dL]/0.7)$^{-0.329}$ × (0.993)$^{(age\ in\ years)}$ |
| | White or other, female, SCr >0.7 | 144 × ([SCr in mg/dL]/0.7)$^{-01.209}$ × (0.993)$^{(age\ in\ years)}$ |
| | White or other, female, SCr ≤0.9 | 141 × ([SCr in mg/dL]/0.7)$^{-0.411}$ × (0.993)$^{(age\ in\ years)}$ |
| | White or other, female, SCr >0.9 | 141 × ([SCr in mg/dL]/0.7)$^{-1.209}$ × (0.993)$^{(age\ in\ years)}$ |

**Abbreviations:** eCrCl, Cockcroft–Gault equation; GFR, glomerular filtration rate; eGFR, glomerular filtration rate; CKD–EPI, CKD–Epidemiology Collaboration equation; SCr, serum creatinine; CKD, chronic kidney disease; MDRD, Modification of Diet in Renal Disease.

literature are based on studies using the CG equation,[22] and many of these recommendations are based on CG before the implementation of standardized SCr. Because drug labeling recommendations for safe and effective dose and regimen adjustments are based on the CG equation, it is customary to use CG for drug-dosing decisions.

Although the current FDA Guidance for Industry recommends the use of CG when designing studies, it does not provide guidance on whether CG should be adjusted for body weight. As a consequence, drug labels usually do not indicate information about whether GFR was adjusted for weight. A systematic review of drug labels approved from 1998–2007 identified 44 labels that recommended dose adjustments based on kidney function; however, only eleven specified that CG should be used and adjusting for body weight was not specified in six of the eleven labels.[24] The original CG formula, published in 1976, used the patient's actual versus adjusted or ideal body weight. Later applications of CG most often adjust for ideal body weight, given the higher body weights of today versus those in 1976. Interestingly, CG adjusted for ideal body weight is less accurate at estimating GFR than unadjusted weight.[5,25–28] CG accurately estimates GFR 66% of the time when adjusted for ideal body weight, compared to 73% of the time when using actual body weight.[37] When using CG for dosing decisions, the decision to adjust for body weight should be based on the method used in the studies that determined the dose adjustment recommendations.

Several studies have compared MDRD with CG for dosing medications. One study evaluated 15 FDA-approved drugs and determined the actual GFR for 5,000 subjects. The study found that MDRD adjusted for BSA (reported as mL/minute) correctly identified dose reductions 88% of the time, while the CG equation accurately calculated the renal dose adjustments 85% and 82% of the time, using actual and ideal body weights, respectively.[27]

In contrast, data from the Can Rapid risk stratification of Unstable angina patients Suppress ADverse outcomes with Early implementation of the ACC/AHA guidelines (CRUSADE) compared CG using ideal body weight with MDRD adjusted for BSA for dosing dose-adjusting antithrombotics for kidney function.[29] This study found that CG led to 43% more cases of antithrombotic dose adjustments than MDRD (30,386 versus 17,329 dose adjustments with CG and MDRD, respectively). Major bleeding occurred in 17.8% and 21.8% of patients who received excessive antithrombotic doses as determined by the CG and MDRD formula, respectively. Minor bleeding events were not reported. Given the narrow therapeutic index of the antithrombotics, the risks of bleeding and increased hospital stays are elevated if the dose is not appropriately adjusted for kidney function. Despite these risks, as well as drug-product labeling and national recommendations to dose adjust antithrombotics based on CG,[21] 87% of hospitals do not follow the drug-labeling recommendations for renal dose adjustments.[30] Another study evaluated dose adjustments in kidney dysfunction for digoxin, another narrow therapeutic index drug. Similar to the results of CRUSADE, this study found that the CG unadjusted for body weight led to 32% more dose reductions of digoxin than MDRD unadjusted for BSA.[31]

Although there are several studies comparing MDRD to CG for drug doses and adverse events, no clinical trials have compared the clinical outcomes of dose and regimen adjustments for patients with CKD on the basis of CG adjusted for ideal body weight compared to unadjusted MDRD. Until more information is available from GFR calculating methods on a comprehensive list of drugs and/or information is available that demonstrates the clinical outcomes associated with these dosing methods, clinicians should dose adjust medications for kidney function based on the methods used in the published studies and package labeling that have been determined to be safe.

## Estimating GFR for staging CKD

Correctly diagnosing and staging CKD is imperative to add appropriate nephroprotective agents and nondrug management to the regimen, to improve vigilance in avoiding nephrotoxic agents, and to screen for and initiate therapies for the common complications of CKD, such as anemia, derangements in electrolytes, and mineral metabolism disorders.

The two most common equations for staging CKD are the MDRD and the CKD–EPI. There is controversy over whether the MDRD or the CKD–EPI is the most appropriate method for estimating GFR for CKD diagnosis, which may stem from a limited knowledge of the new CKD–EPI formula and of the evidence supporting its superiority to MDRD. While MDRD is commonly used for estimating GFR, CKD–EPI is gaining momentum as the optimal GFR estimating equation. In fact, the NKF now recognizes the CKD–EPI formula as more accurate than the MDRD equation, based on head-to-head comparisons of the two formulas.[20] The CKD–EPI equation was specifically developed to overcome the limitations of the MDRD equation.

As a result of differences in study populations used to define the GFR estimating equations, the CKD–EPI equation is as accurate as the MDRD at GFR $<60$ mL/minute and more

accurate than MDRD at GFR >60 mL/minute. The superior accuracy of CKD–EPI across the ranges of GFR has led to a lower estimated prevalence of CKD than that reported with the MDRD (11.5% versus 13.1%). Additionally, more reclassifications of CKD staging to less-severe CKD stages have been reported for patients in the 30–59 mL/minute/1.73 $m^2$ range of GFR (stage 3 CKD).

For example, patients who were originally classified as stage 3 CKD with MDRD may be reclassified as stage 2 by the CKD–EPI equation. When comparing the discordance of CKD staging between MDRD and CKD–EPI, classification by CKD–EPI was correct 65% of the time, compared to MDRD, which was correct only 34% of the time ($P<0.001$).[18]

Relying on the MDRD to screen for CKD decreases the sensitivity and specificity of identifying persons who are near the GFR threshold of 60 mL/minute/1.73 $m^2$ (stage 3 CKD) and decreases the likelihood that CKD staging is accurate. Hence, CKD–EPI is preferred for identifying patients with CKD and for staging the disease. The risk of underestimation of kidney function with MDRD is highest when the GFR is >30 mL/minute/1.73 $m^2$. Therefore, it is especially important to calculate the CKD–EPI for these persons. Using CKD–EPI for diagnosis and staging may more accurately be recommended when the addition of appropriate prophylactic drugs or avoidance of certain nephrotoxic drugs should occur.

## Automation of GFR and HIT

When GFR estimation is automated, the GFR is reported any time that SCr is ordered by clinicians. Although not all laboratories or HIT services automate GFR estimation, there are many benefits to automating GFR estimation. Automation of GFR estimation improves: detection of CKD; appropriate referral to nephrology services; provider reliance on GFR versus SCr alone; and, ultimately, clinical outcomes. Implementation of automated GFR estimation significantly improves identification of CKD by nearly 50%. It also can result in blood pressure goal attainment and the addition of nephroprotective angiotensin-converting enzyme inhibitors or angiotensin receptor blockers to therapy. While the improvements in blood pressure and the addition of nephroprotective agents were statistically significant, the relative percent improvements in achieving these endpoints were found to be modest at 3% and 4.6%, respectively. This may suggest that despite incorporation of HIT services, widespread outcome improvements are not automatic due to patient-related factors, including compliance. Automation can also improve referrals to nephrology by 40%.[32,33] Most importantly, it has been reported that automation of GFR estimation assists in decreasing the decline in GFR from 3.69 mL/minute/1.73 $m^2$ during the 9 months prior to automation to 0.32 mL/minute/1.73 $m^2$ during the 12 months postimplementation ($P<0.001$).[34] The reduction in kidney function decline could have huge benefits for health care costs.

Because of the many benefits of automated GFR estimation, automation is becoming standard of practice. Currently, most laboratories and HIT services that report automated GFR use the MDRD equation. It is important to realize that MDRD reporting may be underestimating the actual GFR. There are many GFR estimating equations and as automation becomes the standard, the automation process needs to clearly identify which GFR formula was coded and reported. Additionally, the variables used in the formula (ideal body weight versus actual body weight) and units of the GFR result (mL/minute versus mL/minute/1.73 $m^2$) need to be clearly identified. Furthermore, it may be useful for automation to include reporting more than one GFR estimation formula, given no one formula is appropriate for all clinical situations. Reporting both CG and either MDRD or CKD–EPI would enhance drug-dosing adjustments as well as enable CKD staging. Choosing the appropriate method for determining GFR is challenging, given the multiple formulas, varying patient care situations in which GFR is used and the complexity of determining the method of kidney function estimation used in the original drug studies or recommended by drug labels. Using clinical decision-support tools within an HIT service that automates GFR estimation could serve a dual purpose to educate providers of which formula is most appropriate to use and how to apply the formula in a given clinical situation.

Within HIT services, it is possible to automatically report estimated GFR using several equations and highlight when each should be used based on the clinical situation. For example, while ordering or refilling dabigatran for a patient with an estimated GFR of 29 mL/minute, the HIT would be programmed with decision support that would pop-up and educate the provider that the dose of dabigatran needs to be reduced or an alternate anticoagulant initiated, because of the patient's estimated GFR. Such decision-support tools are especially helpful for drugs with narrow therapeutic indexes, such as the new oral anticoagulants (dabigatran, enoxaparin, apixaban) and older injectable antithrombotics (enoxaparin) that require renal dose adjustments to prevent bleeding events.

Appropriate dose adjustments for the new oral anticoagulants are especially imperative, because there is currently no reversal agent in the event of excess dose or bleeding. Another such decision-support tool may be a best practice alert that

pops up during an outpatient encounter with a patient who has a CKD–EPI estimated GFR of 58 mL/minute/1.73 $m^2$, and who is not on appropriate renoprotective and cardioprotective agents, such as an angiotensin-converting enzyme inhibitor. This decision-support tool educates the provider at the point of care that the patient should be on certain prophylactic medications, unless there are contraindications.

HIT is increasingly being used for automated GFR estimation reporting. However, there are limitations to the automation of GFR reporting, including inaccurate coding of the equations in the HIT, lack of reference to the equation(s) being used, lack of understanding of the reference equation's clinical limitations, and incorrect interpretation and application of the result. Currently, automation of GFR estimation is typically only reported as MDRD adjusted for BSA, despite the feasibility of incorporating automated reporting of CKD–EPI at most institutions. Automated reporting of MDRD instead of CKD–EPI could contribute to an overdiagnosis of CKD.

## Conclusion

Although there are divergent opinions regarding the best GFR estimation equation to use for the staging of CKD and the dosing of medications, most current data support CKD–EPI as the most accurate method for diagnosis and staging of CKD and CG for drug-dosing decisions. Historically, drug labeling recommendations are based on the CG equation. However, the FDA is considering recommending that both CG and MDRD be incorporated into the drug label.[23] Despite some current confusion regarding GFR estimating equations for CKD staging as opposed to drug dosing, one central element that clinicians should take from this review is that SCr measurements alone should never be used for estimating kidney function. Clinicians need to ensure that HIT services at their institutions convey the necessary level of detail regarding the equation used to report estimated GFR (MDRD versus CKD–EPI versus CG) and the education surrounding the limitations of the estimating equation used. Appropriate estimation of GFR through HIT can improve health outcomes, improve patient safety, and decrease unnecessary health care expenditures.

## Disclosure

The authors report no conflicts of interest in this work.

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