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ORIGINAL ARTICLE

Accuracy of Estimated GFR: Addressing the Elephant in the Room

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Abstract

Background: Accurate assessment of glomerular filtration rate (GFR) is central to nephrology practice, yet measured GFR (mGFR) using exogenous markers is impractical in routine settings. Estimated GFR (eGFR) equations such as the CKD-EPI and MDRD are widely used but have limited validation in Indian populations. This study aimed to compare the accuracy, bias, and precision of CKD-EPI, MDRD, and the indigenous Prabhat formula against mGFR measured by diethylene-triamine-penta-acetic acid (DTPA) scintigraphy. **Methods:** In this prospective single-centre study, 141 adults undergoing DTPA GFR estimation were evaluated. eGFR was calculated using CKD-EPI, MDRD, and Prabhat equations. Accuracy was defined as the percentage of values within ±30% of the reference (P30). Bland–Altman plots were used to determine bias, precision, and relative error. **Results:** The mean DTPA-GFR was 71.2 ± 23.5 mL/min. Mean eGFRs were 85.9 ± 29.4 mL/min for CKD-EPI, 83.9 ± 34.4 mL/min for MDRD, and 68.2 ± 26.4 mL/min for Prabhat. The Prabhat formula showed the highest accuracy (P30 = 74.6%), followed by MDRD (61.1%) and CKD-EPI (57.5%). Bias was lowest with Prabhat (2.5 mL/min), while CKD-EPI demonstrated the best precision (38.5). All three equations correlated strongly with DTPA-GFR (r = 0.65–0.73). **Conclusions:** Although none of the equations met the benchmark P30 ≥ 90%, the Prabhat formula demonstrated superior accuracy, whereas CKD-EPI provided the best precision and least relative error. Validation of region-specific equations such as the Prabhat formula may enhance GFR estimation reliability in Indian patients.

Keywords: eGFR, CKD-EPI, MDRD, Prabhat formula, DTPA, accuracy, bias, precision

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Graphical Abstract

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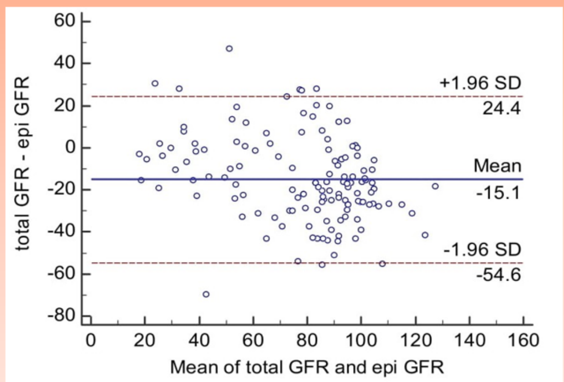
Bland Altman plot of measured GFR as estimated by CKD-EPI equation vs DTPA GFR



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Conclusions Although none of the equations met the benchmark P30 ≥ 90%, the Prabhat formula demonstrated superior accuracy, whereas CKD-EPI provided the best precision and least relative error. Validation of region-specific equations such as the Prabhat formula may enhance GFR estimation reliability in Indian patients.

Key Points

- Estimated GFR equations such as CKD-EPI and MDRD were developed in Western populations and show reduced accuracy in Indian adults.
- In this cohort of 141 individuals, the indigenous Prabhat equation demonstrated the highest accuracy (P30 = 74.6%) and the lowest bias compared with DTPA-measured GFR.
- CKD-EPI and MDRD significantly overestimated renal function, leading to potential misclassification of CKD stage.
- Population-specific calibration of GFR estimation equations is necessary in regions with different anthropometry and dietary patterns.
- Inaccurate GFR estimation may affect CKD staging, drug dosing, donor evaluation, and clinical decision-making.

Introduction

The estimation of glomerular filtration rate (GFR) through various equations is integral to routine nephrology practice. Because direct measurement of GFR (mGFR) using exogenous filtration markers is impractical in most clinical settings, estimated GFR (eGFR) is widely preferred. Among the available equations, the Modification of Diet in Renal Disease (MDRD) formula was long regarded as the standard, but it has largely been superseded by the Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) equation, which offers greater accuracy at GFR values above 60 mL/min/1.73 m². However, the CKD-EPI equation has not been extensively validated across diverse populations, and data from the Indian subcontinent remain limited.

The present study aimed to assess the accuracy and precision of commonly used eGFR equations compared with mGFR determined by diethylenetriaminepentaacetic acid (DTPA) scintigraphy and to evaluate an indigenous simplified equation, the Prabhat formula.

Methods

This single-centre, prospective study was conducted over two years (October 2018 – October 2020) and included 141 consecutive patients who attended the nephrology outpatient clinic, in whom accurate assessment of GFR was considered clinically necessary by the treating physician. Eligible participants were adults aged ≥ 30 years and included renal donors, patients with single kidneys, congenital anomalies of the kidney and urinary tract, or established chronic kidney disease (CKD). Exclusion criteria comprised pregnancy, acute kidney injury (AKI) with unstable renal function, kidney transplant recipients, and patients on dialysis. Demographic and clinical data—including age, sex, comorbidities, underlying renal diagnosis, and serum creatinine—were recorded for all participants. All subjects underwent GFR measurement using technetium-99m diethylenetriaminepentaacetic acid (Tc-99m DTPA) scintigraphy.

Method of creatinine estimation

Serum creatinine was measured using kinetic compensated Jaffe assay traceable to isotope dilution mass spectrometry determination in Cobas 8000 analyzer (Roche Diagnostics GmbH Mannheim, Germany).

Method of dynamic renal scintigraphy

Following breakfast, patients were instructed to drink 300–500 mL of water. A bolus of 185 MBq (megabecquerels) of technetium-99m-labelled diethylenetriaminepentaacetic acid (Tc-99m DTPA) was then administered intravenously. The syringe containing Tc-99m DTPA was measured for radioactivity before and after injection, and the total injected dose was calculated. The injection site was scanned using a gamma camera, and dynamic scintigraphy images were acquired over 30 minutes at 2-minute intervals. At the 20-minute mark, furosemide (0.5–1 mg/kg body weight, maximum 40 mg) was injected intravenously, followed by immediate post-void and delayed (2-hour) imaging. GFR values (mL/min) were derived using the Gates method, applying the equation:

GFR = 9.75621 × Fractional unit − 6.19843. Measured GFR obtained from Tc-99m DTPA scintigraphy was expressed as absolute GFR (mL/min). Estimated GFR values derived from the CKD-EPI, MDRD, and Prabhat equations were compared directly with these measured values without body surface area normalization.

Equations used for GFR estimation

CKD -EPI Formula used – calculated using NKF online calculator

- GFR = 141 * min(Scr/κ,1)$^{\alpha}$ * max(Scr/κ, 1)$^{-1.209}$ * 0.993^{Age} * 1.018 [if female] * 1.159 [if black]

Scr is serum creatinine (mg/dL), κ is 0.7 for females and 0.9 for males, α is -0.329 for females and -0.411 for males, min indicates the minimum of Scr/κ or 1, and max indicates the maximum of Scr/κ or 1.

CKD MDRD 4 variable formula used – calculated using NKF online calculator

GFR in mL/min per 1.73 m^2 = 175 x SerumCr$^{-1.154}$ x age$^{-0.203}$ x 1.212 (if patient is black) x 0.742 (if female)

The equation Prabhat's formula is expressed as:

- CrCl = 100/(1.3 × S. Creatinine) × (0.8 if female) if age is between 30 and 40 years
- CrCl = 100/(1.5 × S. Creatinine) × (0.8 if female) if age is between 41 and 50 years
- CrCl = 100/(1.8 × S. Creatinine) × (0.8 if female) if age >50 years.

Statistical analysis

Statistical analysis was performed using SPSS version 17.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation (SD). The performance of the different eGFR equations was evaluated in terms of accuracy, bias, and precision. Accuracy was defined as the proportion of eGFR values falling within ± 30% of the measured GFR by Tc-99m DTPA (P30). Agreement between eGFR and mGFR values was assessed using Bland–Altman plots. Bias was defined as the mean difference between estimated and measured GFR values. Precision was assessed by the standard deviation of the bias, reflecting the spread of differences around the mean bias. Relative error was calculated as twice the standard deviation of the bias divided by the mean measured GFR.

Results

Complete paired DTPA and estimated GFR data were available for 139 participants for CKD-EPI and MDRD analyses and 138 participants for the Prabhat formula. A total of 141 patients met the inclusion criteria and were included in the analysis. The mean age of the cohort was 47.3 ± 11.0 years, and 53.2% were male. The most common comorbidity was chronic kidney disease (52.4%), followed by diabetes mellitus (17.0%) and hypertension (14.9%). The mean serum creatinine was 1.04 ± 0.66 mg/dL. In most patients, renal function was marginally higher in the right kidney than in the left (50.4% vs 49.5%, respectively). The most frequent indication for DTPA evaluation was renal donor assessment (16.3%), followed by pelvi-ureteric junction obstruction (8.5%) and renal stone disease (6.4%) (Table 1).

The mean total GFR measured by DTPA was 71.2 ± 23.5 mL/min. Among the estimation equations, the CKD-EPI equation produced the highest mean eGFR (85.9 ± 29.4 mL/min), followed by the MDRD (83.9 ± 34.4 mL/min) and Prabhat (68.2 ± 26.4 mL/min) equations. The mean difference from the reference standard was smallest for the Prabhat formula (2.5 mL/min) and greatest for the CKD-EPI equation (−15.1 mL/min), with MDRD showing an intermediate bias of −13.1 mL/min.

Table 1. Baseline characteristics of the study population

Characteristic	Value (Percentage/ SD) (n=141)
Mean age of study population	47.26 (SD 10.96)
Sex	
Male	75 (53.2%)
Female	66 (46.8%)
Co-morbidities	

Chronic Kidney disease	74 (52.4%)
Diabetes	24 (17%)
Hypertension	21 (14.9%)
Coronary artery disease	9 (6.3%)
Hypothyroidism	5 (3.5%)
COPD (chronic obstructive	1 (0.7%)
Pulmonary disease)	2 (1.4%)
Malignancy	1 (0.7%)
Obstructive Sleep Apnea	1 (0.7%)
Chronic gastritis	1 (0.7%)
Cervical spondylosis	1 (0.7%)
Amyloidosis	
Mean creatinine	1.04mg/dl (SD 0.66)
Differential renal function (DTPA)	
Left mean function	49.53% (SD 23.25)
Right mean function	50.38% (SD 23.24)
Disease	Value (percent)
Renal donor	23 (16.3%)
PUJ (pelvi-uretric junction)	12 (8.5%)
obstruction	9 (6.4%)
Renal stone disease	5 (3.5%)
Chronic kidney disease unknown	5 (3.5%)
Pyelonephritis	2 (1.4%)
Renal artery stenosis	3 (2.1%)
Stricture ureter	2 (1.4%)
Single Kidney	2 (1.4%)
Non-functioning kidney	1 (0.7%)
Congenital Mega-ureter	1 (0.7%)
Horseshoe kidney	1 (0.7%)
Crossed ectopic kidney	1 (0.7%)
Bladder neck hypertrophy	1 (0.7%)
Xanthogranulomatous pyelonephritis	1 (0.7%)
Carcinoma Bladder	1 (0.7%)
RCC kidney (Renal Cell Carcinoma)	1 (0.7%)
Genito-urinary tuberculosis	1 (0.7%)
Vesico-ureteric reflux	1 (0.7%)
Hydro-ureteronephrosis without	1 (0.7%)
obstruction	
Vesical calculus	

Table 2. Mean GFR estimated by different methods

GFR estimation method	Mean GFR (SD) N=141	Difference between the means from DTPA (SD)
DTPA mean total GFR	71.21ml/min (23.46)	
Left kidney	34.59ml/min (18.06)	
Right kidney	36.63ml/min (18.94)	
Mean GFR by CKD-EPI equation	85.89ml/min (29.38)	-15.09 (20.17)
Mean GFR by MDRD	83.87ml/min (34.37)	-13.07 (26.09)
Mean GFR by Prabhat formula	68.15ml/min (26.37)	2.53 (19.98)
Mean difference for overestimation from DTPA GFR (Standard Deviation)		**Significance – (2 tailed) for t test equality of means**
CKD-EPI GFR	13.68 (11.31)	0.00
GFR – MDRD	15.50 (12.47)	0.00
Prabhat formula	16.43 (13.10)	0.00
Mean difference for under-estimation from DTPA GFR (Confidence Intervals)		
CKD-EPI GFR	-23.01 (13.86)	0.00
GFR – MDRD	- 23.05 (21.88)	0.00
Prabhat formula	-14.02 (12.83)	0.00

Table 3. Correlation, bias, precision and accuracy between the different GFR estimation equations using DTPA as the gold standard

	CKD-EPI	MDRD GFR	Prabhat formula GFR
Total GFR (DTPA)			
Pearson correlation	0.73	0.65	0.68
Significance 2-tailed (significant at 0.01)	0.00	0.00	0.00
ICC (95% CI)	0.83 (0.77-0.88)	0.76 (0.66-0.83)	0.81 (0.73-0.86)
Bias	-15.09 (20.171)	-13.07 (26.01)	2.52 (19.98)
Precision	38.54	51.14	39.16
Relative error	0.512	0.67	0.57
Accuracy p30	57.55%	61.1%	74.63%

Table 4. Reclassification of CKD stages using CKD-EPI, MDRD, and Prabhat equations compared with DTPA-derived CKD stage

	Stage 1 (n= 34)	Stage 2 (n=67)	Stage 3 (n=28)	Stage 4 (n=8)	Stage 5 (n=2)	Overall 139
Percentage retained in same stage CKD-EPI	25 (73.5%)	13 (19.4%)	13 (46.4%)	4 (50%)	0	55 (39.56%)
Percentage moved up CKD-EPI	0	51 (76.2%)	13 (46.4%)	4 (50%)	2 (100%)	70 (50.3%)
Percentage moved down CKD-EPI	9 (26.5%)	3 (4.5%)	2 (7.1%)	0	0	14 (10.1%)
Percentage retained in same stage MDRD equation	22 (64.7%)	27 (40.3%)	14 (50%)	5 (62.5%)	0	68 (48.9)%
Percentage moved up MDRD equation	0	33 (49.3%)	11 (39.2%)	3 (37.5%)	2 (100%)	49 (35.2%)
Percentage moved down MDRD equation	12 (35.3%)	7 (10.4%)	3 (10.71%)	0	0	22 (15.8%)
Percentage retained in same stage	9 (27.3%)	43 (64.2%)	15 (53.6%)	6 (75%)	0	73 (52.9%).

Prabhat formula						
Percentage moved up Prabhat formula	24 (72.7%)	10 (14.9%)	5 (17.9%)	0	0	39 (28.3%)
Percentage moved down Prabhat formula	0	14 (20.9%)	8(28.6%)	2 (25%)	2 (100%)	26 (18.8%)

The CKD-EPI equation demonstrated the strongest correlation with DTPA-GFR (r = 0.73), followed by the Prabhat (r = 0.68) and MDRD (r = 0.65) equations (Table 3). In terms of accuracy, defined by P30, the Prabhat formula performed best (74.6%), followed by MDRD (61.1%) and CKD-EPI (57.6%). Bland–Altman analysis showed that the Prabhat formula exhibited the lowest bias (2.5 ± 20.0 mL/min), whereas CKD-EPI demonstrated marginally better precision than the Prabhat formula. MDRD showed the greatest imprecision and the widest limits of agreement (−64.2 to 38.1). Relative error values were lowest for CKD-EPI (0.51), followed by the Prabhat formula (0.57) and MDRD (0.67) (Figure 2a, b and c).

Based on DTPA-derived GFR, most patients were classified as having CKD stage 2 (Figure 1). When eGFR was determined using CKD-EPI or MDRD, many patients originally classified as stage 2 were reclassified as stage 1. Conversely, use of the Prabhat formula resulted in more patients being shifted from stage 1 to lower CKD stages. Overestimation of GFR occurred in 77% of cases using CKD-EPI and 73% using MDRD, whereas the Prabhat formula demonstrated greater concordance with DTPA staging, with 52.9% of patients remaining within the same CKD stage (Table 4).

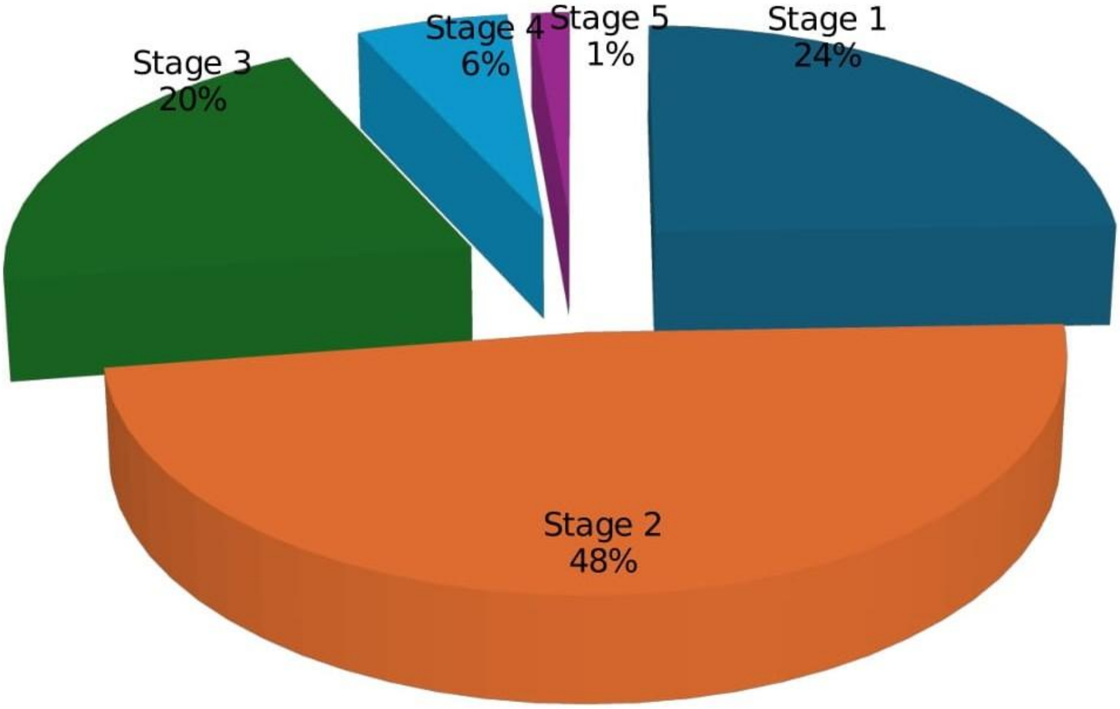

Figure 1. Pie chart with frequency of patients according to CKD Stage as classified by DTPA

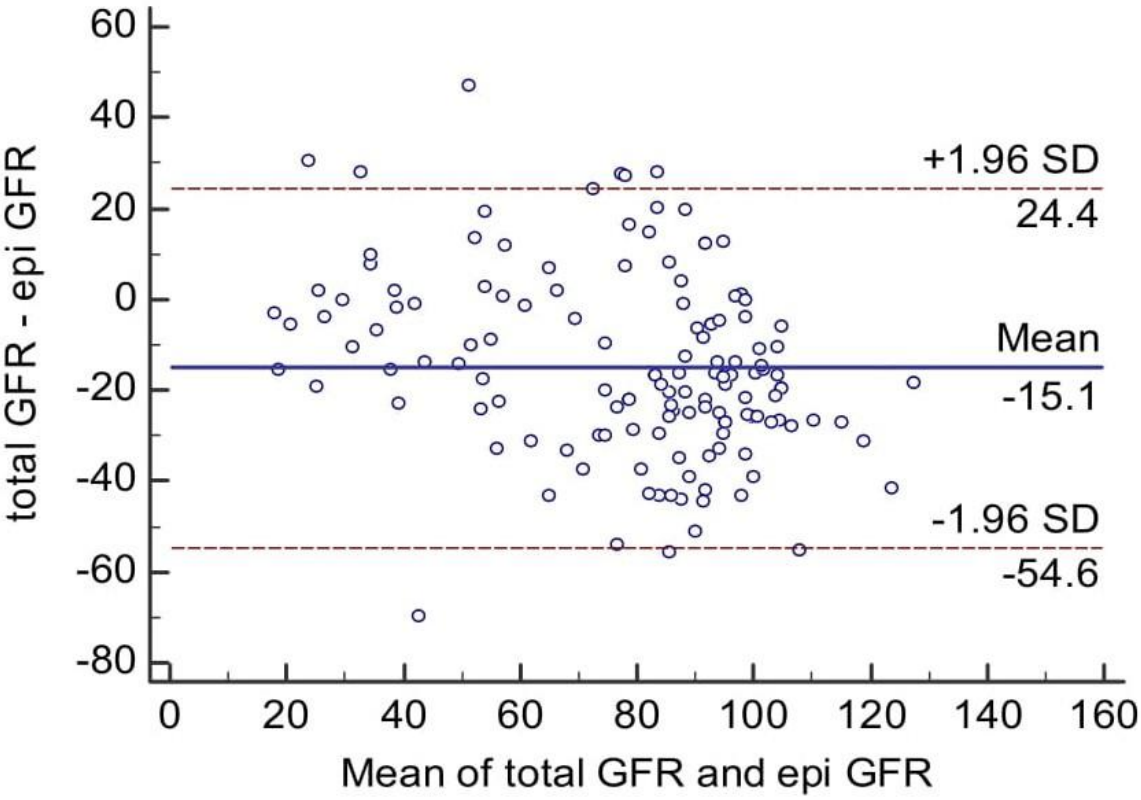

Figure 2a. Bland Altman plot of measured GFR as estimated by CKD-EPI equation vs DTPA GFR

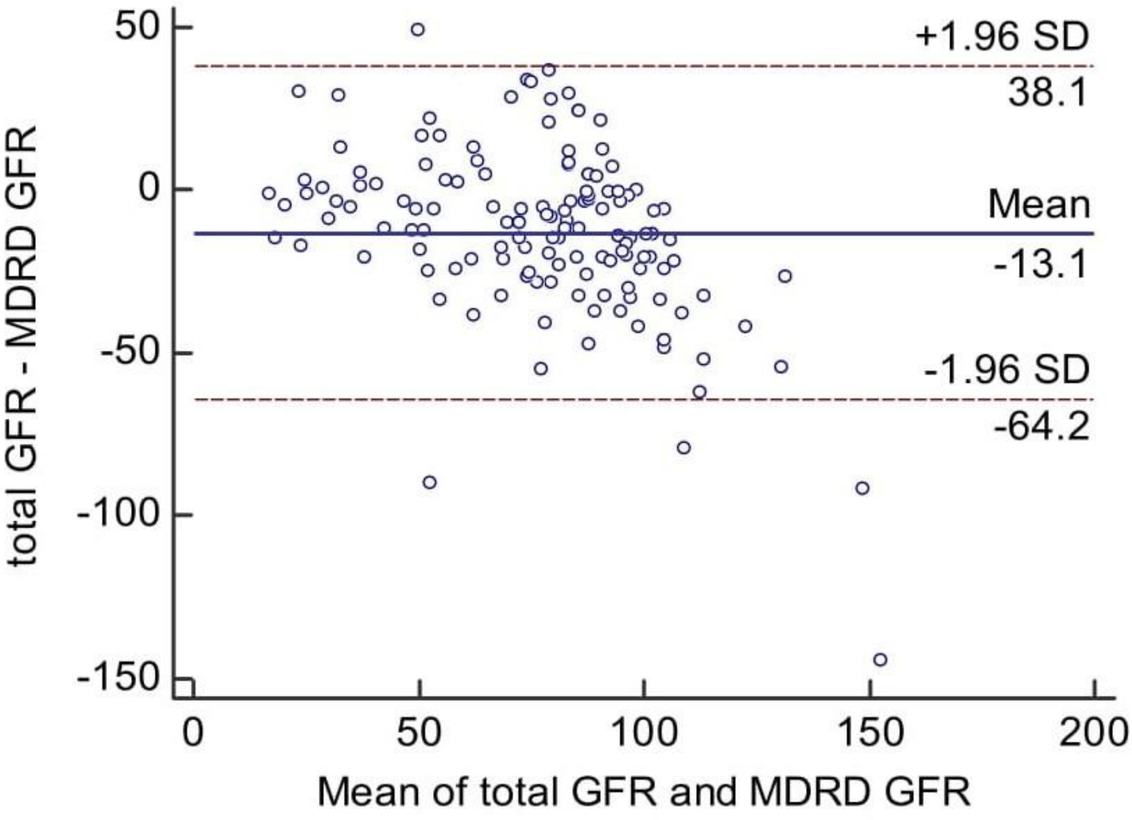

Figure 2b. Bland Altman plot of measured GFR as estimated by MDRD equation vs DTPA GFR

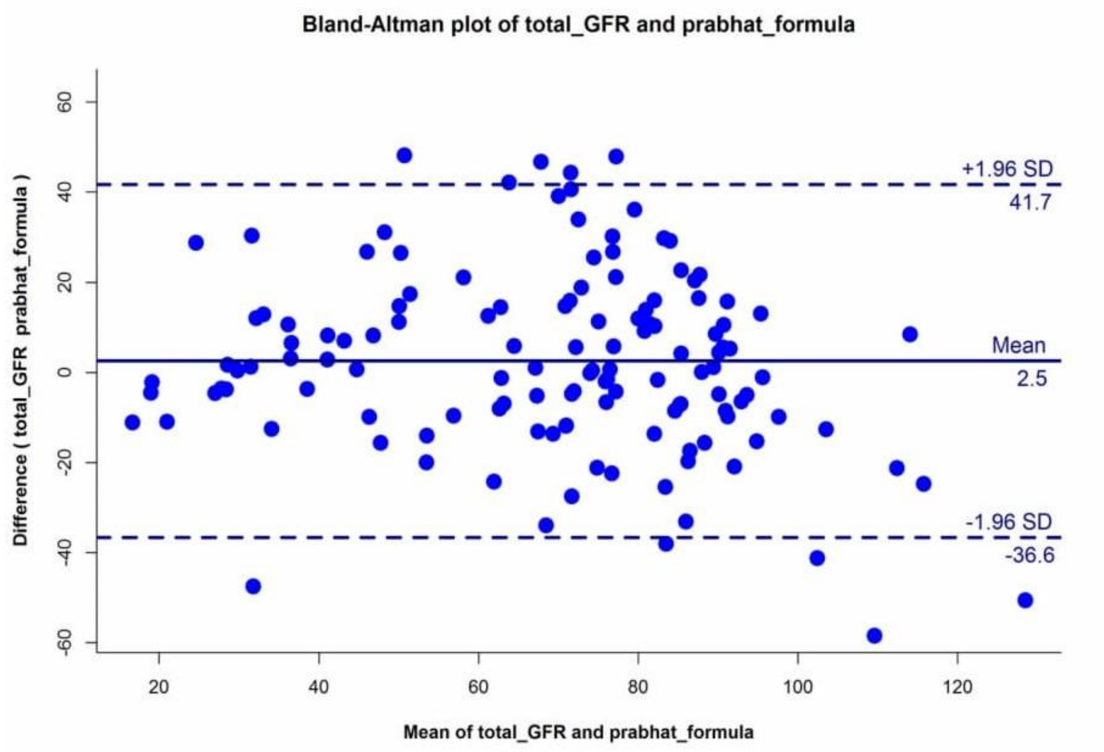

Figure 2c. Bland Altman plot of measured GFR as estimated by Prabhat formula vs DTPA GFR

Discussion

Why the need for a new formula for GFR estimation and what is the Prabhat formula?

Over the past several decades, more than 70 equations for estimating glomerular filtration rate (eGFR) have been developed. As described by Porrini et al. although these equations have evolved, their accuracy and precision have not markedly improved [1]. Most existing formulas achieve a P30—defined as the proportion of values lying within 30% of the reference standard—of only around 40%. Despite these limitations, the MDRD and CKD-EPI equations remain the most widely used worldwide. However, each has inherent shortcomings related to population specificity, bias, and precision [2]. Ethnic and environmental factors also affect equation performance, prompting the development of region-specific modifications.

The Prabhat formula was proposed as a simplified, indigenous alternative designed to make GFR estimation easier in clinical settings [3]. Its simplicity and local derivation are appealing features, but it has not previously undergone formal validation.

In addition, all creatinine-based estimation equations share certain intrinsic limitations. Serum creatinine is influenced by non-GFR determinants such as muscle mass, diet, age, sex, and medication use [4]. Alternative filtration markers like cystatin C, while promising, are themselves affected by inflammatory states and certain drugs, limiting their reliability in routine clinical use.

The study population

Cohorts of patients undergoing DTPA studies are often heterogeneous, comprising both renal donors and individuals with kidney disease. In the study by Ocampo et al., which compared various GFR estimation methods, the most common indication for DTPA scanning was donor evaluation [5]. In our study, the mean age of participants was 47.2 years—approximately a decade older than those in other reported cohorts. This difference likely reflects the inclusion of both healthy and diseased individuals, rather than a purely donor population. Data from a South Indian centre evaluating renal donors have previously demonstrated laterality differences in renal function, with mean GFRs of 47.7 mL/min on the right and 43.4 mL/min on the left [6]. A similar finding was observed in our cohort, with slightly higher function on the right side.

Difference between mean GFR estimated by various equations and measured GFR

In this study, the mean GFR estimated by the CKD-EPI equation was higher than that derived from both other estimation methods and the measured DTPA GFR. The mean difference between the DTPA GFR (reference standard) and each estimation equation was smallest for the Prabhat formula, followed by the MDRD and CKD-EPI equations (Table 2).

Both the CKD-EPI and MDRD equations frequently overestimated GFR when compared with DTPA measurements, whereas the Prabhat formula more often underestimated GFR. The degree of overestimation by CKD-EPI was greatest among patients with CKD stages II, IV, and V, and a similar trend was noted with the MDRD equation. In contrast, the Prabhat formula demonstrated a distinct pattern, with underestimation in CKD stages I and III and overestimation in stages IV and V.

These findings were unexpected, as the MDRD equation is generally known to underestimate GFR in individuals with preserved renal function (GFR > 60 mL/min/1.73 m²)—a limitation that led to the widespread adoption of the CKD-EPI equation. One possible explanation is that the accuracy of an equation may vary according to the underlying clinical profile of the population. Murata et al. reported that CKD-EPI had lower bias than MDRD in potential kidney donors, whereas MDRD performed better among patients with CKD [7]. Because the present cohort included both donors and patients with kidney disease, this heterogeneity may have influenced the results.

Additionally, racial and dietary factors could contribute to discrepancies between measured and estimated GFR. Both CKD-EPI and MDRD equations were developed primarily in Western populations and have not been extensively validated in Indian cohorts. Variations in body composition and habitual low protein intake in Indian populations may partially explain the differences observed when these equations are applied locally.

Correlation, accuracy, precision and bias between DTPA GFR and estimation equations

In this study, all three equations—CKD-EPI, MDRD, and the Prabhat formula—demonstrated good correlation with measured DTPA GFR. The CKD-EPI equation showed the highest Pearson correlation coefficient ($r = 0.73$), followed by the Prabhat ($r = 0.68$) and MDRD ($r = 0.65$) equations (Table 3). Similarly, Malik et al. reported comparable findings, with r values of 0.40 for CKD-EPI, 0.39 for MDRD, and −0.03 for the Cockcroft–Gault equation [8].

Although correlation was good in this cohort, it is not the ideal metric for assessing the performance of GFR estimation equations. For such comparisons, accuracy, precision, and bias are more relevant indicators. Accuracy refers to the closeness of an estimated value to the true value. In this study, accuracy was expressed as the proportion of eGFR results within ± 30% of the DTPA-measured GFR (P30). By international convention, a P30 ≥ 90% is considered the benchmark for acceptable accuracy, although this threshold is largely based on expert opinion [9]. Some researchers have proposed adopting a stricter criterion, such as P10, which would require 90% of estimates to fall within 10% of the reference value.

In the present study, the Prabhat formula demonstrated the highest accuracy (P30 = 74.6%), followed by the MDRD (61.1%) and CKD-EPI (57.5%) equations. These findings are comparable to previously published data: Jeong *et al.* reported P30 values of 60.7% for CKD-EPI at mGFR < 60 mL/min and 91.7% at higher GFRs [10], while a Congolese cohort showed P30 values of 86% for CKD-EPI and 81.7% for MDRD [11]. In an Indian study by Kumar et al., the CKD-EPI and MDRD equations had P30 values of 22.3% and 25.4%, respectively [8].

Bland–Altman analysis further quantified the degree of agreement between the equations and the reference method. The limits of agreement that were published by Kakde et al earlier for a cohort of Indian donors showed limits of agreement and accuracy similar to this study [12]. The Prabhat formula exhibited the narrowest limits of agreement and the lowest bias (2.52 mL/min), followed by MDRD (−13.07 mL/min) and CKD-EPI (−15.09 mL/min). The biases reported in this study were larger than those in other Asian cohorts—for example, Teo et al. found a bias of −1.17 mL/min in a Singapore population that included patients of Indian origin [13].

Precision, which reflects reproducibility, was highest for the CKD-EPI equation (38.54) and lowest for the MDRD equation (51.14), with the Prabhat formula showing intermediate precision (39.16). The degree of imprecision observed here is greater than that reported in most East Asian studies, where interquartile ranges (IQRs) for precision typically fall between 15 and 20. In the Singapore study including Indian participants, the IQR was 13.7, indicating substantially better reproducibility.

The relative error in this study was 0.51 for CKD-EPI, 0.67 for MDRD, and 0.57 for the Prabhat formula. Among the evaluated equations, CKD-EPI demonstrated the lowest relative error, suggesting comparatively better consistency despite its larger bias.

Strengths and limitations of the current study

The principal strength of this study is that it evaluates and compares three commonly used eGFR equations—including an indigenous formula— against the reference DTPA method within the same patient cohort. To our knowledge, this is one of the few Indian studies to directly assess the performance of the Prabhat equation. The sample size of 141 participants provides adequate statistical power to identify clinically meaningful differences between estimation methods. Furthermore, by including both healthy renal donors and patients with varying degrees of kidney disease, the study captures a broad spectrum of GFR values, thereby improving generalizability to real-world nephrology practice.

However, several limitations should be acknowledged. First, the study was conducted at a single centre, which may limit external validity. Second, the heterogeneous nature of the cohort, which included both healthy renal donors and patients with diverse renal pathologies, may also have influenced the performance characteristics of the individual estimation equations across subgroups. Third, although DTPA scintigraphy is an accepted reference method, it is less precise than inulin or iothalamate clearance, which are considered the definitive gold standards for measuring GFR. Fourth, because the study excluded individuals with acute kidney injury, the results may not apply to patients with rapidly changing renal function. Finally, muscle mass, dietary factors, and body surface area were not uniformly quantified, all of which can influence creatinine-based estimates.

Despite these limitations, the findings highlight the potential clinical relevance of region-specific equations, such as the Prabhat formula, in improving the accuracy of GFR estimation among Indian patients.

Conclusion

The current study demonstrates that while all three estimation equations—CKD-EPI, MDRD, and the Prabhat formula—correlate reasonably well with measured GFR, their accuracy and precision remain suboptimal when compared with the reference DTPA method. Among them, the Prabhat formula showed the highest overall accuracy (P30 = 74.6%), whereas the CKD-EPI equation demonstrated the best precision and lowest relative error. None of the equations, however, achieved the internationally accepted accuracy threshold of P30 ≥ 90%.

These findings underscore the need for continued refinement and validation of GFR estimation equations in diverse ethnic and geographic populations. Given that creatinine-based equations are influenced by multiple non-GFR determinants—including muscle mass, diet, and medication use—future work should explore combined creatinine–cystatin C models or incorporate novel biomarkers and machine-learning approaches for better precision.

The results of this study support the concept that locally derived, population-specific equations, such as the Prabhat formula, may improve the accuracy of renal function assessment in Indian patients. Multicentric studies with larger sample sizes and direct comparison against inulin clearance are warranted to confirm these observations and to establish optimal tools for clinical application.

Statements and Disclosures

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Conflict of Interest

The authors declare that they have no conflicts of interest relevant to this article.

Ethical Approval

The study was approved by the Institutional Ethics Committee of Sri Ramachandra Institute of Higher Education and Research, Chennai (Approval No. CSP-MED/19/FEB/50/24).

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AI Usage Declaration

Artificial intelligence tools were not used for data analysis or content generation. Language refinement and formatting assistance were provided using ChatGPT (OpenAI, USA) under the supervision of the corresponding author.

Author Contributions

NJ, Conceptualization, study design, data collection, data analysis, interpretation of results, manuscript drafting, and final approval; JV, Conceptualization, supervision, critical revision of the manuscript, and final approval; IE, Data interpretation, assistance in study conduct, and review of the manuscript; TM, Statistical analysis, data interpretation, and review of the manuscript; VE, Contribution to DTPA GFR methodology and data acquisition, and review of the manuscript; MJ, Critical revision of the manuscript, intellectual input, and final approval. All authors have read and approved the final manuscript.

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