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# Comparison of the 2021 and 2009 chronic kidney disease epidemiology collaboration creatinine equation for estimated glomerular filtration rate in a Chinese population

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ABSTRACT

*Objectives:* To retrospectively compare the clinical effects of the newly released 2021 and 2009 Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) equations for estimated glomerular filtration rate based on creatinine (eGFRcr) in a Chinese population with a broad spectrum of clinical characteristics using historical data.

*Design and methods:* Patients and healthy individuals who visited the Zhongshan Hospital, Fudan University, between July 1, 2020, and July 1, 2022, were enrolled. The exclusion criteria were age < 18 years, amputees, pregnant women, patients with muscle-related diseases, and patients who had undergone ultrafiltration or dialysis. The final study population included 1,051,827 patients with a median age of 57 years; 57.24% of the enrolled individuals were men. eGFRcr was calculated using the 2009 and 2021 CKD-EPI equations and initial creatinine level. Results were evaluated statistically by sex, age, creatinine level, and CKD stage.

*Results:* The 2021 equation increased the eGFRcr in all participants compared to the 2009 equation by 4.46%. The median eGFRcr deviation of the 2021 CKD-EPI equation compared to the 2009 CKD-EPI equation was 4 ml/min/1.73 $m^2$. 903,443 subjects (85.89%) had higher eGFRcr owing to the utilization of the 2021 CKD-EPI equation, which did not cause CKD stage change. A total of 11.57% of subjects (121,666) had improved CKD stage with the 2021 CKD-EPI equation. 1.79% (18,817) had the same CKD stage with both equations, and 0.75% (7,901) had lower eGFRcr but no change in the CKD stage with the 2021 equation.

*Conclusions:* The 2021 CKD-EPI equation typically produces higher eGFRcr results than the 2009 version. Applying the new equation could lead to changes in the CKD stage for some patients, which doctors should consider.

## 1. Introduction

The glomerular filtration rate (GFR) plays an important role in the diagnosis and prognosis of chronic kidney disease (CKD) and is a key indicator for evaluating renal function. The gold standard for GFR determination, the measured glomerular filtration rate (mGFR) is labor-intensive and not commonly used in clinical applications. The estimated glomerular filtration rate (eGFR), calculated based on endogenous filtration markers such as creatinine or cystatin C according to a specific equation, is recommended as the first choice for renal function evaluation [1–4]. Over the past three decades, eGFR based on creatinine (eGFRcr) has been widely used in clinical laboratories. Since the Cockcroft–Gault equation was introduced in 1976 [5], researchers have developed more than 70 eGFR equations. The CKD Epidemiology

*Abbreviations:* CKD-EPI, Chronic Kidney Disease Epidemiology; eGFRcr, estimated glomerular filtration rate based on creatinine; CKD, chronic kidney disease; mGFR, measured glomerular filtration rate; Scr, serum creatinine; KDIGO, Kidney Disease: Improving Global Outcomes; eGFRcys, eGFR based on cystatin C.

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Collaboration (CKD-EPI) eGFRcr equation was introduced in 2009 [6]. The CKD-EPI equation was established in a population including patients with CKD, healthy individuals, and transplant patients of various ethnic groups and a wide age distribution. Thus, CKD-EPI equations have a wider range of applications and are more suitable for individuals with a relatively high GFR; it is the most recommended equation in clinical practice [7,8]. In 2012, the CKD-EPI equation was developed based on cystatin C (eGFRcys) or its combination with creatinine (eGFRcr-cys) [9,10].

The CKD-EPI 2009 eGFRcr and 2012 eGFRcr-cys equations, as well as the modified diet for renal disease [11] and other equations, contain the ethnic coefficients of black and non-black individuals, which improves the accuracy of the eGFRcr in these two groups of people. However, in the past few years, because race represents a social rather than a biological structure, considering race as a coefficient in the equation may ignore the diversity of intra- and inter-ethnic groups. Therefore, the appeal for eliminating the race coefficient from the equation has become stronger [4,12–14]. Recently, the CKD-EPI redesigned the equation to remove the ethnic coefficient and published the new 2021 CKD-EPI eGFRcr and eGFRcr-cys equations in the New England Journal of Medicine in November 2021 [15]. This study stated that the new equation without the ethnic coefficient underestimated the black eGFR and slightly overestimated the non-black eGFR. The 2021 CKD-EPI eGFRcr.cys was more accurate than the eGFRcr equation, and the discrepancy between different ethnic groups was smaller [15,16]. In 2022, all American clinical laboratories were recommended to promptly use the 2021 CKD-EPI eGFRcr equation without an ethnic coefficient [17].

This study is the first to evaluate the 2021 CKD-EPI equation without considering the ethnic coefficients in the Chinese population. We compared the 2021 and 2009 CKD-EPI equations and assessed the impact of the new equation on CKD staging. This study provides necessary data to promote the clinical application of the 2021 CKD-EPI eGFRcr equation in a Chinese population with a broad spectrum of clinical characteristics using historical data.

## 2. Patients and methods

### 2.1. Design and participants

A total of 1,051,827 patients (median age 57 [43,67]) years; males, 602,106 [57.3%]) who visited Zhongshan Hospital, Fudan University from July 1, 2020, to July 1, 2022, were enrolled in the study after excluding patients who were younger than 18 years old, amputees, pregnant women, patients who had muscle-related diseases, or had undergone ultrafiltration and dialysis. The first serum creatinine (Scr) result for each patient was used for eGFRcr calculation.

### 2.2. Methods

Serum creatinine (Scr) was measured using an enzymatic reaction method (Cobas c702, Roche Diagnostics, Suisse) traceable to isotope dilution mass spectrometry; the result was reported in μmol/L [17].

### 2.3. Categories according to the eGFR results

The eGFRcr results were calculated by 2009 and 2021 CKD-EPI equations [15]. The eGFR delta values were obtained as the results of the 2021 CKD-EPI equation minus those of the 2009 CKD-EPI equation.

CKD staging was conducted based on the Evaluation and Management of Chronic Kidney Disease: Synopsis of Kidney Disease: Improving Global Outcomes (KDIGO) 2012 Clinical Practice Guideline [7,18–20].

### 2.4. Ethics statement

This study was approved by the ethics committee of Zhongshan Hospital Affiliated with Fudan University (approval Number: B2022-466) for human studies, and the patients signed an informed consent form.

### 2.5. Statistical analysis

All data were analyzed using IBM SPSS Statistics 25.0. The Kolmogorov–Smirnov test of independent samples was used for the normality test. Normal distribution data were expressed as mean ± standard deviation, and non-normal distribution measurement data were expressed as median (Q1, Q3).

## 3. Results

### 3.1. Basic data of the enrolled population

A total of 1,051,827 participants were evaluated in this study, including 602,106 males and 449,721 females aged 18–106. The 2021 equation increased the eGFRcr in all participants compared to the 2009 equation by 4.46%±1.83% and by 3.7(2.9,4.5) ml/min/1.73 $m^2$. Table 1 presents the study population's clinical characteristics and basic laboratory data. The eGFRcr stratification was defined according to the KDIGO guidelines based on CKD stages.

### 3.2. Distribution of CKD stage variations between two equations

Fig. 1 shows the distributions of the eGFRcr results calculated using the 2009 and 2021 CKD-EPI equations for all participants. The eGFRcr values of the 2021 CKD-EPI equation were higher than those of the 2009 CKD-EPI equation. According to the 2009 CKD-EPI equation, the proportions of CKD stages 1–5 in the study population were 53.2%, 36.1%, 5.6%, 2.5%, 1.2%, and 1.2%, respectively. Using the 2021 CKD-EPI equation, the proportions of patients with CKD stages 1–5 were 62.1%, 29%, 4.5%, 2.1%, 1.1%, and 1.2%, respectively. The most significant discrepancy between the two equations was in the CKD G1 stage. The proportion of G1, based on the 2021 equation, was 8.9% higher than that of the 2009 equation. The median value of eGFRcr tended to increase from 91 ml/min/1.73 $m^2$ using the 2009 CKD-EPI to 95 ml/min/1.73 $m^2$ using the 2021 CKD-EPI equation.

### 3.3. eGFRcr variations between two equations

The changes in the 2021 CKD-EPI eGFRcr compared to the 2009 CKD-EPI eGFRcr in the enrolled population are shown in Table 2. A total of 1,025,109 participants (97.46%) had higher 2021 CKD-EPI eGFRcr results than the 2009 equation results, which presented a median increment of 4 ml/min/1.73 $m^2$, and these participants were distributed in all stages of CKD. A total of 18,817 participants (1.79%) had the same eGFRcr results between the two equations, concentrated in the lower three CKD stages, namely CKD G5, G4, and G3b. In total, 7,901 participants (0.75%) had lower eGFRcr calculated by the 2021 CKD-EPI equation, with a median decrease of 2 ml/min/1.73 $m^2$ and a maximum reduction of 13 ml/min/1.73 $m^2$ compared with the 2009 equation. This part of the population was concentrated in the G1 stage of CKD.

### 3.4. Delta values of eGFRcr between two equations

The eGFRcr delta values of the 2021 CKD-EPI equation minus the 2009 CKD-EPI equation for each sex and age group are shown in Fig. 2. With an increase in the 2009 eGFRcr, the delta values gradually increased at first and then decreased. When the 2009 eGFRcr increased to more than 100, the delta values decreased to negative values. This trend was more evident in men than in women. Furthermore, a higher degree of deviation was observed in older individuals.

The highest delta value of men was 6.3 ml/min/1.73 $m^2$, which appeared at the age of 94, and 2009 eGFRcr of 73 ml/min/1.73 $m^2$; The

**Table 1**
Clinical characteristics and basic laboratory data of the enrolled population (n = 1,051,827).

| | Total population | 2009 CKD-EPI eGFRcr ( ml/min/1.73 $m^2$) | | | | | |
|---|---|---|---|---|---|---|---|
| | | G1 ≥90 | G2 60–89 | G3a 45–59 | G3b 30–44 | G4 15–29 | G5 <15 |
| Age | 57 (43,67) | 48 (36,59) | 65 (55,71) | 69 (61,77) | 70 (60,79) | 68 (56,77) | 62 (50,71) |
| Sex (Male) | 602,106 (57.24%) | 292,047 (52.16%) | 241,039 (63.40%) | 37,943 (63.89%) | 15,959 (59.62%) | 7316 (58.42%) | 7802 (59.56%) |
| Creatinine (μmol/L) | 76 (63,90) | 65 (57,76) | 84 (73,95) | 113 (99,124) | 145 (128,164) | 223 (191,265) | 681 (471,958) |
| 2009 CKD-EPI eGFRcr ( mL/min/1.73 $m^2$) | 91 (76,102) | 101 (95,110) | 79 (72,85) | 53 (49,57) | 39 (35,42) | 23 (19,27) | 6 (4,10) |
| 2021 CKD-EPI eGFRcr ( mL/min/1.73 $m^2$) | 95 (81,106) | 105 (99,113) | 84 (76,89) | 57 (53,60) | 41 (37,45) | 25 (21,28) | 7 (4,10) |

CKD-EPI: Chronic Kidney Disease Epidemiology Collaboration; eGFRcr: estimated glomerular filtration rate based on creatinine.
Data are presented as the median (Q1,Q3) and number (percentage).

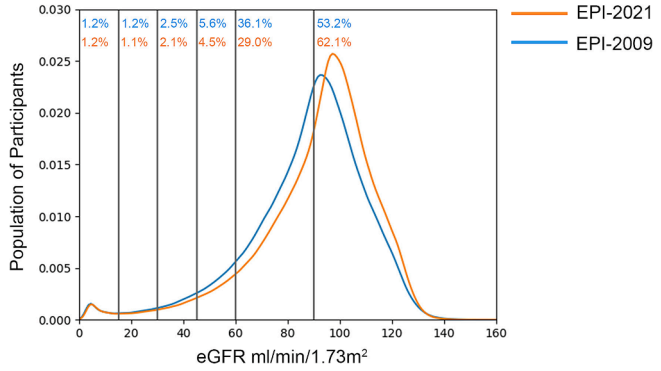


**Fig. 1.** Distribution of the eGFRcr results of the 2009 and 2021 CKD-EPI equations in all the participants. CKD-EPI: Chronic Kidney Disease Epidemiology Collaboration, eGFRcr: estimated glomerular filtration rate based on creatinine.

lowest delta value was −12.5 ml/min/1.73 $m^2$, which occurred at the age of 29 and 2009 eGFRcr of 172 ml/min/1.73 $m^2$.

The highest delta value of women was 5.8 ml/min/1.73 $m^2$, which appeared at the age of 97, and 2009 eGFRcr of 73 ml/min/1.73 $m^2$, the lowest value was −7.1 ml/min/1.73 $m^2$, which occurred at the age of 18 and 2009 eGFRcr of 158 ml/min/1.73 $m^2$.

### 3.5. CKD stage reclassification by 2021 CKD-EPI equation

To investigate the influence of the 2021 CKD-EPI equation on the CKD stage in the study population, the reclassification of total enrolled participants caused by differences between the 2009 and 2021 CKD-EPI equations was analyzed (Fig. 3).

Of all subjects, 11.57% (121,666/1051827) had higher eGFRcr, which resulted in a one-stage improvement in CKD stage based on the 2021 CKD-EPI equation compared to that based on the 2009 CKD-EPI equation. No subjects defined as CKD stage 1 by the 2009 CKD-EPI equation changed stages when using the 2021 CKD-EPI equation. In each of the CKD stages 2–5 defined by the 2009 CKD-EPI equation, 24.7% (93,782/380158), 31.0% (18,430/59388), 25.2% (6,741/26767), 16.7% (2,086/12523), and 4.8% (627/13099) of participants, respectively, improved due to the 2021 CKD-EPI equation.

### 3.6. CKD stage reclassification according to gender and age groups

The distributions of the participants' age and creatinine levels at each CKD stage defined by the 2009 CKD-EPI equation are presented in Fig. 4. It also highlighted men and women whose CKD stages improved by one grade due to using the 2021 CKD-EPI equation. As expected, in the same age group, creatinine levels, which could result in an improved CKD stage for women, were lower than those for men. Creatinine levels, which could cause CKD stage changes, decreased with increasing age.

## 4. Discussion

Since the 2021 CKD-EPI equation without the race coefficient was published, it has attracted widespread attention. The Clinical Chemistry journal published an application guide for clinical laboratories to use the 2021 CKD-EPI eGFR equation [17]. It is recommended that all clinical laboratories in the United States promptly use the 2021 new equation with no race coefficient. The guidelines considered that the performance and consequences of the potential application of the new equation were acceptable and that there was no disproportionate impact on any group of individuals. The clinical application of the 2021 new equation needs to be verified in a large population of multiple races. To our knowledge, this is the first study to investigate the difference and reclassification between the 2021 and 2009 equations in a substantial Chinese population, including outpatients, inpatients, and physical examination populations.

When the population was fixed as Chinese in this study, the deviations between the two equations were affected by sex, age, and

**Table 2**
2021 CKD-EPI eGFRcr changes compared with the 2009 CKD-EPI eGFRcr in the entire enrolled population.

| | 2009 CKD-EPI eGFRcr (ml/min/1.73 $m^2$) | | | | | | Total |
|---|---|---|---|---|---|---|---|
| | G1 ≥90 | G2 60–89 | G3a 45–59 | G3b 30–44 | G4 15–29 | G5 <15 | |
| 2021 eGFRcr higher | 539,792 (51.32%) | 380,158 (36.14%) | 59,388 (5.65%) | 26,763 (2.54%) | 12,363 (1.18%) | 6645 (0.63%) | 1,025,109 |
| 2021 eGFRcr unchanged | 12,199 (1.16%) | / | / | 4 (0.00%) | 160 (0.02%) | 6454 (0.61%) | 18,817 |
| 2021 eGFRcr lower | 7901 (0.75%) | / | / | / | / | / | 7901 |
| Total | 559,892 | 380,158 | 59,388 | 26,767 | 12,523 | 13,099 | 1,051,827 |

CKD-EPI: Chronic Kidney Disease Epidemiology Collaboration; eGFRcr: estimated glomerular filtration rate based on creatinine level.

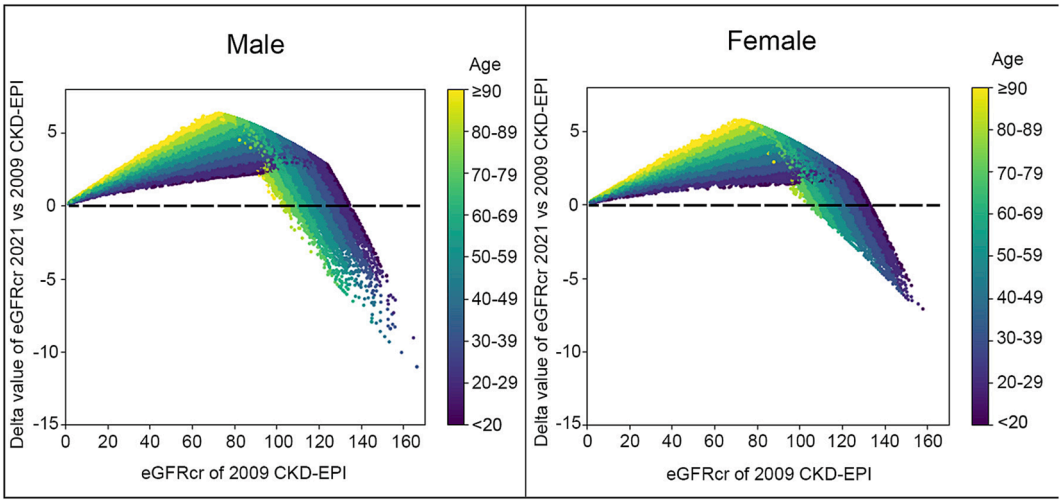


**Fig. 2.** Overall trends of the absolute difference between the eGFRcr of the 2021 minus 2009 CKD-EPI equations according to the sex and age of the participants. CKD-EPI: Chronic Kidney Disease Epidemiology Collaboration, eGFRcr: estimated glomerular filtration rate based on creatinine.

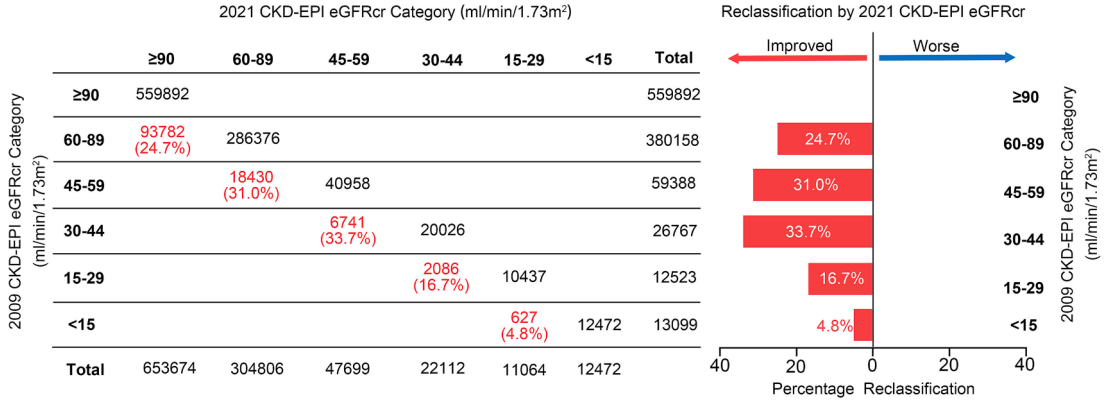


**Fig. 3.** The 2009 and 2021 CKD-EPI eGFRcr equations were applied to all the participants with different proportions of CKD stages. CKD-EPI: Chronic Kidney Disease Epidemiology Collaboration, eGFRcr: estimated glomerular filtration rate based on creatinine.

creatinine levels. The 2021 CKD-EPI eGFRcr results were higher than those of 2009; however, the deviations were slight. The average deviation between the 2021 and 2009 equations was 4.46%, which is consistent with the 4.72% obtained in another study [21]. The median eGFRcr deviation of the 2021 CKD-EPI equation compared to the 2009 CKD-EPI equation was 4 ml/min/1.73 $m^2$. Therefore, the two equations showed a good correlation in the Chinese population in this study.

The annual decline of eGFR in healthy individuals is approximately 0.5 ml/min/1.73 $m^2$. The eGFR level of patients with hypertension, diabetes, urinary tract infection, and other complications decreases more with age. For patients with CKD, the decline in eGFR accelerates with the progression of CKD stage [18]. Changes in eGFRcr levels resulting from the 2021 CKD-EPI equation and pathophysiological factors may affect the treatment and monitoring of patients, especially considering the short-term follow-up of patients.

Although 97.46% of all participants had higher 2021 CKD-EPI eGFRcr results than the 2009 equation results, only 11.57% of subjects with higher eGFRcr showed improvement by one CKD stage distributed between G2 and G5. It is important to note that patients' CKD stage was changed due to using different equations, especially in patients with eGFRcr close to 60 ml/min/1.73 $m^2$, which is the diagnostic criterion of CKD [7,20]. In this study, 18430(1.75%) patients had 2009 CKD-EPI eGFRcr $<$ 60 ml/min/1.73 $m^2$ and 2021 eGFRcr $\geq$ 60 ml/min/1.73 $m^2$, which was similar to another Asian study result (2.2%) [22]. Compared with the 2009 creatinine equation, the 2021 creatinine equation, but not the new creatinine-cystatin C equation, increased population estimates of CKD prevalence among blacks and yielded similar or lower prevalence among non-blacks [15]. A Korean study showed that conversion of the eGFR equation would significantly change the prevalence of CKD [23]. Applying the 2021 CKD-EPI equation would have the greatest impact on this section of patients. CKD stage improvement would simultaneously reduce the societal medical burden and delay diagnosis and treatment. Communication between clinicians and patients is still deemed necessary.

A total of 0.75% of the subjects had a lower eGFRcr in the 2021 CKD-EPI equation compared to 2009 CKD-EPI equation. However, all change degree of these eGFRcr results were not enough to cause a worse stage of CKD. After applying the 2021 CKD-EPI equation, the lowest eGFRcr results of those people were 103 ml/min/1.73 $m^2$, still characterized in G1. Therefore, none of the lower eGFRcr results caused a change from G1 to G2, which had no impact on the CKD stage and clinical judgment.

Currently, eGFR based on serum creatinine levels is still widely used in clinical laboratories worldwide. The KDIGO guidelines and the original Kidney Disease Outcomes Quality Initiative guidelines point out that the renal function of patients should be evaluated in combination with Scr concentration and eGFR. The KDIGO guidelines also emphasized the limitations of eGFRcr. When the non-GFR determinants of the Scr concentration were different from those of the study participants who established the equation, the accuracy of the eGFRcr was relatively low. These conditions include changes in creatinine production (such as

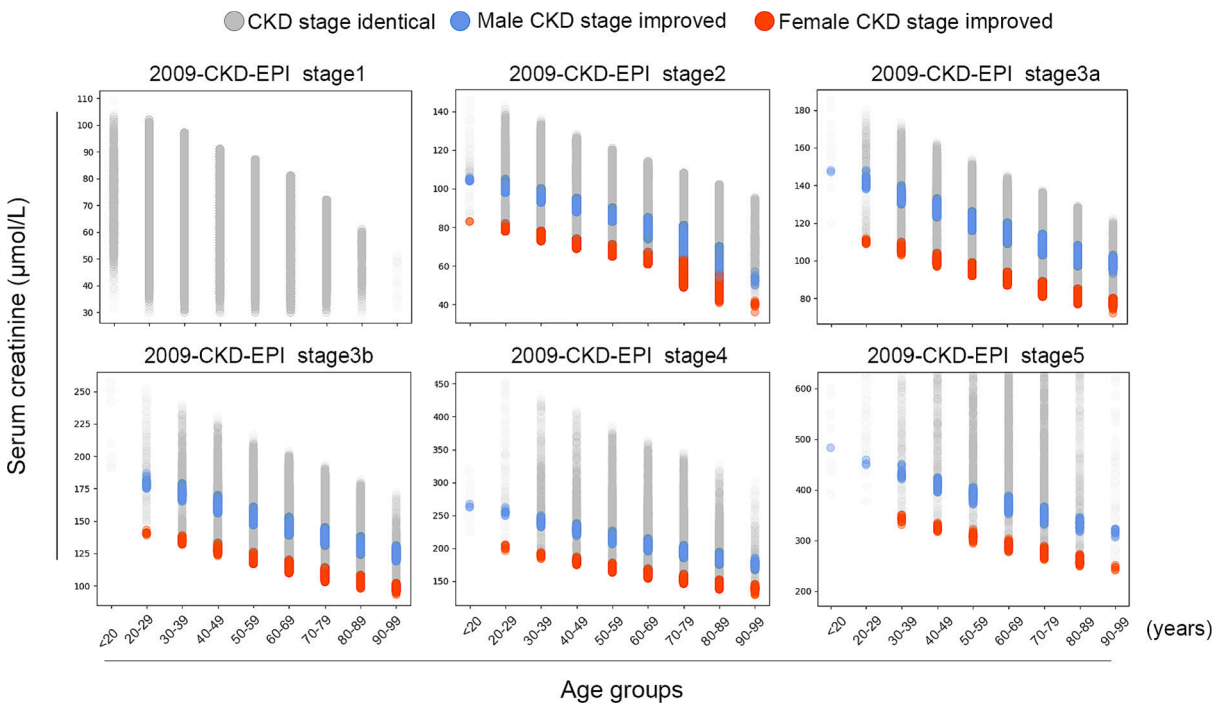


**Fig. 4.** Distribution of the age and creatinine levels in different stages of CKD in the study population. CKD: chronic kidney disease.

in vegetarians) and the consumption of drugs that inhibit creatinine secretion [2,3]. Therefore, serum cystatin C and mGFR levels are recommended.

Few studies have shown that the CKD-EPI eGFRcys-cr performs better than CKD-EPI eGFRcr and CKD-EPI eGFRcys in estimating the GFR [24,25]. Other studies [15,26] demonstrated that large individual differences may still exist between eGFR results and mGFR after applying the 2021 CKD-EPI equation. There is no obvious improvement after applying the cystatin C-based eGFR equation. When evaluating the renal function of patients with type 2 diabetes, the performance of the CKD-EPI equation was not ideal [27]. In healthy Brazilian adults, different equations presented larger biases, worse agreement with mGFR, and inferior accuracy, with 2021 CKD-EPI (83%) and European Kidney Function Consortium (EKFC) (82%) presenting greater percentage of estimates<30% different from measured GFR (P30) than Full Age Spectrum (FAS) (77%) [28]. The KDIGO guidelines recommend that the P30 should be greater than 90%. However, most eGFR equations do not fulfill this requirement [29].

We would compare the differences between the 2012 and 2021 equations of CKD EPI eGFRcys and eGFRcys-cr in a follow-up study. The performance of these two equations among the whole population and certain disease groups (such as diabetic nephropathy) would be analyzed.

## 5. Conclusions

The eGFRcr results calculated using the 2021 CKD-EPI equation were generally higher than those calculated using the 2009 CKD-EPI equation. The application of the new equation could result in the improvement of the CKD stage of patients, which should be taken into consideration by physicians.

## CRediT authorship contribution statement

**Yifeng Shen:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. **Hao Wu:** Methodology, Software, Formal analysis, Visualization, Data curation, Writing – review & editing. **Xiaowen Liu:** Conceptualization, Methodology, Investigation. **Jing Zhu:** Conceptualization, Methodology, Validation, Writing – original draft. **Wenqi Shao:** Methodology, Validation, Resources, Supervision. **Beili Wang:** Conceptualization, Methodology, Supervision, Resources. **Baishen Pan:** Conceptualization, Methodology, Supervision, Project administration, Writing – review & editing. **Wei Guo:** Conceptualization, Methodology, Supervision, Project administration.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## References

[1] J.R. Ingelfinger, A.S. Levey, M.E. Grams, L.A. Inker, Uses of GFR and albuminuria level in acute and chronic kidney disease, N. Engl. J. Med. 386 (22) (2022) 2120–2128.
[2] L.A. Inker, S. Titan, Measurement and Estimation of GFR for Use in Clinical Practice: Core Curriculum 2021, Am. J. Kidney Dis. 78 (5) (2021) 736–749.
[3] A.S. Levey, J. Coresh, H. Tighiouart, T. Greene, L.A. Inker, Measured and estimated glomerular filtration rate: current status and future directions, Nat. Rev. Nephrol. 16 (1) (2020) 51–64.
[4] A.S. Levey, S.M. Titan, N.R. Powe, J. Coresh, L.A. Inker, Kidney Disease, Race, and GFR Estimation, Clin. J. Am. Soc. Nephrol. 15 (8) (2020) 1203–1212.
[5] D.W. Cockcroft, M.H. Gault, Prediction of creatinine clearance from serum creatinine, Nephron 16 (1) (1976) 31–41.

[6] A.S. Levey, L.A. Stevens, C.H. Schmid, Y.L. Zhang, A.F. Castro 3rd, H.I. Feldman, J. W. Kusek, P. Eggers, F. Van Lente, T. Greene, J. Coresh, E.P.I. Ckd, A new equation to estimate glomerular filtration rate, Ann. Intern. Med. 150 (9) (2009) 604–612.
[7] P.E. Stevens, A. Levin, M., Kidney Disease: Improving Global Outcomes Chronic Kidney Disease Guideline Development Work Group, Evaluation and management of chronic kidney disease: synopsis of the kidney disease: improving global outcomes 2012 clinical practice guideline, Ann. Intern. Med. 158 (11) (2013) 825–830.
[8] K. Matsushita, B.K. Mahmoodi, M. Woodward, J.R. Emberson, T.H. Jafar, S.H. Jee, K.R. Polkinghorne, A. Shankar, D.H. Smith, M. Tonelli, D.G. Warnock, C.P. Wen, J. Coresh, R.T. Gansevoort, B.R. Hemmelgarn, A.S. Levey, C., Chronic Kidney Disease Prognosis, Comparison of risk prediction using the CKD-EPI equation and the MDRD study equation for estimated glomerular filtration rate, J. Am. Med. Assoc. 307 (18) (2012) 1941–1951.
[9] L.A. Inker, C.H. Schmid, H. Tighiouart, J.H. Eckfeldt, H.I. Feldman, T. Greene, J. W. Kusek, J. Manzi, F. Van Lente, Y.L. Zhang, J. Coresh, A.S. Levey, C.-E. Investigators, Estimating glomerular filtration rate from serum creatinine and cystatin C, N. Engl. J. Med. 367 (1) (2012) 20–29.
[10] J.W. Meeusen, A.D. Rule, N. Voskoboev, N.A. Baumann, J.C. Lieske, Performance of cystatin C- and creatinine-based estimated glomerular filtration rate equations depends on patient characteristics, Clin. Chem. 61 (10) (2015) 1265–1272.
[11] A.S. Levey, J. Coresh, T. Greene, L.A. Stevens, Y.L. Zhang, S. Hendriksen, J. W. Kusek, F. Van Lente, C., Chronic Kidney Disease Epidemiology, Using standardized serum creatinine values in the modification of diet in renal disease study equation for estimating glomerular filtration rate, Ann. Intern. Med. 145 (4) (2006) 247–254.
[12] C.Y. Hsu, W. Yang, R.V. Parikh, A.H. Anderson, T.K. Chen, D.L. Cohen, J. He, M. J. Mohanty, J.P. Lash, K.T. Mills, A.N. Muiru, A. Parsa, M.R. Saunders, T. Shafi, R. R. Townsend, S.S. Waikar, J. Wang, M. Wolf, T.C. Tan, H.I. Feldman, A.S. Go, C. S. Investigators, Race,, Genetic Ancestry, and Estimating Kidney Function in CKD, N. Engl. J. Med. 385 (19) (2021) 1750–1760.
[13] K.C. Norris, N.D. Eneanya, L.E. Boulware, Removal of Race From Estimates of Kidney Function: First, Do No Harm, JAMA 325 (2) (2021) 135–137.
[14] J.A. Diao, L.A. Inker, A.S. Levey, H. Tighiouart, N.R. Powe, A.K. Manrai, In Search of a Better Equation - Performance and Equity in Estimates of Kidney Function, N. Engl. J. Med. 384 (5) (2021) 396–399.
[15] L.A. Inker, N.D. Eneanya, J. Coresh, H. Tighiouart, D. Wang, Y. Sang, D.C. Crews, A. Doria, M.M. Estrella, M. Froissart, M.E. Grams, T. Greene, A. Grubb, V. Gudnason, O.M. Gutierrez, R. Kalil, A.B. Karger, M. Mauer, G. Navis, R. G. Nelson, E.D. Poggio, R. Rodby, P. Rossing, A.D. Rule, E. Selvin, J.C. Seegmiller, M.G. Shlipak, V.E. Torres, W. Yang, S.H. Ballew, S.J. Couture, N.R. Powe, A. S. Levey, C., Chronic Kidney Disease Epidemiology, New Creatinine- and Cystatin C-Based Equations to Estimate GFR without Race, N. Engl. J. Med. 385 (19) (2021) 1737–1749.
[16] C. Delgado, M. Baweja, N.R. Burrows, D.C. Crews, N.D. Eneanya, C.A. Gadegbeku, L.A. Inker, M.L. Mendu, W.G. Miller, M.M. Moxey-Mims, G.V. Roberts, W.L. St Peter, C. Warfield, N.R. Powe, Reassessing the Inclusion of Race in Diagnosing Kidney Diseases: An Interim Report From the NKF-ASN Task Force, Am. J. Kidney Dis. 78 (1) (2021) 103–115.
[17] W.G. Miller, H.W. Kaufman, A.S. Levey, J.A. Straseski, K.W. Wilhelms, H.E. Yu, J. S. Klutts, L.H. Hilborne, G.L. Horowitz, J. Lieske, J.L. Ennis, J.L. Bowling, M. J. Lewis, E. Montgomery, J.A. Vassalotti, L.A. Inker, National Kidney Foundation Laboratory Engagement Working Group Recommendations for Implementing the CKD-EPI 2021 Race-Free Equations for Estimated Glomerular Filtration Rate: Practical Guidance for Clinical Laboratories, Clin. Chem. 68 (4) (2022) 511–520.
[18] L.A. Inker, B.C. Astor, C.H. Fox, T. Isakova, J.P. Lash, C.A. Peralta, M. Kurella Tamura, H.I. Feldman, KDOQI US commentary on the 2012 KDIGO clinical practice guideline for the evaluation and management of CKD, Am. J. Kidney Dis. 63 (5) (2014) 713–735.
[19] T.A. Ikizler, J.D. Burrowes, L.D. Byham-Gray, K.L. Campbell, J.-J. Carrero, W. Chan, D. Fouque, A.N. Friedman, S. Ghaddar, D.J. Goldstein-Fuchs, G. A. Kaysen, J.D. Kopple, D. Teta, A. Yee-Moon Wang, L. Cuppari, KDOQI Clinical Practice Guideline for Nutrition in CKD: 2020 Update, Am. J. Kidney Dis. 76 (3) (2020) S1–S107.
[20] F. National Kidney, K/DOQI clinical practice guidelines for chronic kidney disease: evaluation, classification, and stratification, Am. J. Kidney Dis. 39 (2 Suppl 1) (2002) S1–266.
[21] C.V. Schneider, K.M. Schneider, New Equations for Estimating the GFR without Race, N. Engl. J. Med. 386 (17) (2022) 1671–1672.
[22] B.K. Betzler, R. Sultana, F. He, Y.C. Tham, C.C. Lim, Y.X. Wang, V. Nangia, E.S. Tai, T.H. Rim, M.M. Bikbov, J.B. Jonas, S.W. Kang, K.H. Park, C.Y. Cheng, C. Sabanayagam, Impact of Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) GFR Estimating Equations on CKD Prevalence and Classification Among Asians, Front Med (Lausanne) 14 (9) (2022 Jul), 957437.
[23] H. Kim, M. Hur, S. Lee, G.-H. Lee, H.-W. Moon, Y.-M. Yun, European Kidney Function Consortium Equation vs. Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) Refit Equations for Estimating Glomerular Filtration Rate: Comparison with CKD-EPI Equations in the Korean Population, J. Clin. Med. 11 (15) (2022) 4323.
[24] X.H. Chi, G.P. Li, Q.S. Wang, Y.S. Qi, K. Huang, Q. Zhang, Y.M. Xue, CKD-EPI creatinine-cystatin C glomerular filtration rate estimation equation seems more suitable for Chinese patients with chronic kidney disease than other equations, BMC Nephrol. 18 (1) (2017) 226.
[25] I. Masson, N. Maillard, I. Tack, L. Thibaudin, L. Dubourg, P. Delanaye, E. Cavalier, C. Bonneau, N. Kamar, E. Morelon, O. Moranne, E. Alamartine, C. Mariat, GFR estimation using standardized cystatin C in kidney transplant recipients, Am. J. Kidney Dis. 61 (2) (2013) 279–284.
[26] T. Shafi, X. Zhu, S.T. Lirette, A.D. Rule, T. Mosley, K.R. Butler, M.E. Hall, P. Vaitla, J.J. Wynn, M.C. Tio, N.R. Dossabhoy, E. Guallar, J. Butler, Quantifying Individual-Level Inaccuracy in Glomerular Filtration Rate Estimation : A Cross-Sectional Study, Ann. Intern. Med. 175 (8) (2022) 1073–1082.
[27] S. Luis-Lima, T. Higueras Linares, L. Henríquez-Gómez, R. Alonso-Pescoso, A. Jimenez, A.M. López-Hijazo, N. Negrín-Mena, C. Martín, M. Sánchez-Gallego, S. J. Galindo-Hernández, R. Socas Fernández del Castillo, M. Castilla-Marrero, S. Domínguez-Coello, V. Vilchez de León, R. Valcárcel-Lopez, N. Insausti-Garmendia, B. Escamilla, S. Estupiñán, P. Delgado-Mallén, A.-M. Armas-Padrón, D. Marrero-Miranda, A. González-Rinne, R.M. Miquel Rodríguez, M.A. Cobo-Caso, L. Díaz-Martín, F. González-Rinne, A. González-Delgado, M. López-Martínez, A. Jiménez-Sosa, A. Torres, E. Porrini, The Error of Estimated GFR in Type 2 Diabetes Mellitus, J. Clin. Med. 8 (10) (2019) 1543.
[28] L.C.F. Silva, B.M. Rocha, G.M. Escott, I.F. Porgere, L.A. Tochetto, L. de Almeida Brondani, S.P. Silveiro, Accuracy evaluation of 2021 Chronic Kidney Disease Epidemiology Collaboration, Full Age Spectrum and European Kidney Function Consortium equations for estimating glomerular filtration rate in type 2 diabetes mellitus and healthy adults, Clin. Chim. Acta 534 (2022) 14–21.
[29] E.J. Lamb, P.E. Stevens, Estimating and measuring glomerular filtration rate: methods of measurement and markers for estimation, Curr. Opin. Nephrol. Hypertens. 23 (3) (2014) 258–266.