Original Article

Determining an accurate method to estimate GFR in renal transplant recipients with stable serum creatinine levels

Subramanyam Padma and Palaniswamy Shanmuga Sundaram

Department of Nuclear Medicine and Molecular Imaging, Amrita Institute of Medical Sciences and Research Center, Cochin, Kerala, India

(Received 5 August 2019, Revised 22 October 2019, Accepted 26 October 2019)

ABSTRACT

Introduction: Detecting renal allograft dysfunction early will allow timely diagnosis and treatment. There is no objective recommendation by national kidney societies for glomerular filtration rate (eGFR) estimation in post-transplant setting. ^{99m}Tc-DTPA Technetium-99m Diethylene triamine penta acetic acid) renogram can identify early renal dysfunction much before serum creatinine levels get deranged. Our objectives are: 1) We hypothesised that if Gates formula is depth corrected for anteriorly placed renal allograft, can it serve as a reliable, accurate investigation 2) To compare how DTPA renogram with depth correction (CT based) and without depth correction (fixed distance) fares with creatinine based MDRD (Modification of Diet in Renal Disease), and CKD-EPI Chronic Kidney Disease Epidemiology Collaboration) equations in transplant recipients in our population. GFR values were compared with gold standard venous blood GFR single sampling method in a few patients.

Methods: Forty adults live related adult renal allograft recipients with serum creatinine values of less than 2.0 mg/dl at 6 months follow-up were enrolled.

Results: Mean measured GFR was calculated for 4 different methods along with single plasma sampling method. MDRD and CKD-EPI equations showed higher values in our study but correlated well with each other in GFR estimation. Accuracy was highest with GFR derived from depth corrected DTPA renogram (69.2%) than for fixed depth method (60 %, p ¼ 0.0012). GFR obtained by DTPA depth correction method also showed good correlation to SPSM.

Conclusion: ^{99m}Tc-DTPA based GFR estimation with depth correction is not affected by serum creatinine level and showed highest accuracy.

Key words: ^{99m}Tc-DTPA renogram; Transplant renogram; Glomerular filtration rate; Creatinine; Single plasma sample method

Iran J Nucl Med 2020;28(1):21-27
Published: January, 2020
http://irjnm.tums.ac.ir

Corresponding author: Dr. Subramanyam Padma, Department of Nuclear Medicine and Molecular Imaging, Amrita Institute of Medical Sciences & Research Centre, Cochin-6802041, Kerala, India. E-mail: padmas@aims.amrita.edu

INTRODUCTION

GFR is considered as the best index of renal graft function and also a predictor of graft and patient survival. A rise in blood creatinine levels is observed only after significant loss of functioning nephrons [1]. DTPA renogram based Gates GFR (Glomerular filtration rate) estimation is simple, cost effective, widely available procedure but is criticised due to its varying accuracy. Technically GFR obtained from Gates method is meant for native kidneys and not for anterior placed transplanted grafts. Plasma creatinine estimation is invariably the first investigation to be performed, but is unreliable and can be erroneous due to many variables. In an effort to seek the right investigation, researchers from different countries have used mathematical formulas in an attempt to standardise the estimated GFR (eGFR) in their respective patient population. These formulas have been endorsed by the National Kidney Foundation Disease Outcomes Quality Initiative (K-DOQI) [1]. And they recommend use of estimates of GFR calculated from prediction equations based on plasma or serum creatinine in patients with suspected or confirmed renal diseases. Majority of eGFR comparisons using equations / blood sample, camera based DTPA renogram in literature have been performed in patients with native kidneys. We hypothesised that if Gates formula is depth corrected can it serve as a reliable, accurate, simple, technically robust investigation which can be used for GFR estimation in transplant recipients. GFR estimation using inulin clearance is considered the gold standard. Radionuclide tracers like ^{51}Cr-EDTA, ^{125}I-Iothalamate have been used in the past for GFR estimation [2]. But due to its non-availability, expense and complexity of these tests, the search is still on to determine the right investigative marker for GFR estimation.

MTHODS

This is a prospective study of 40 males (age 18 to 50 years) who underwent live related adult renal transplantation for chronic renal disease in our institute from 2014 to 2016. All patients underwent ^{99m}Tc-DTPA renogram 6 months after a successful renal transplant. As renal depths slightly differ between males and females, and there exists a difference in creatinine ranges between males and females, we included males of same ethnicity. Other inclusion parameters were; body weight between 40 to 72 kilograms, non-diabetics, first time allograft recipients with serum creatinine values of less than 2.0 mg/dl at the time of DTPA renogram.

The inclusion criteria applied were strict to ensure that factors like sex, age, gender, ethnicity, body weight, creatinine value are minimized and will not significantly affect the outcome of this study. After ensuring adequate (500 – 1000 ml) oral hydration 3-4 hours prior, patients were taken up for ^{99m}Tc-DTPA renogram in our department. 296 MBq of ^{99m}Tc-DTPA was injected intravenously in antecubital vein while patient was in supine position. GE Optima NM/ CT 640 gamma camera was used. Anterior abdominal images were acquired at 128 x 128 matrix size using low energy high resolution parallel hole collimator with an energy window at 140 KeV(+/- 10%). Dynamic images were acquired at 2 seconds per frame for 60 seconds followed by 15 seconds per frame for the next 30 minutes. Static pre-void, post void and delayed images are acquired for 300 kilo counts.

Non contrast CT abdomen was performed in all patients for graft depth assessment. Renal depths were assessed in transaxial and sagittal planes by measuring the distance between the skin and the anterior as well as the lateral surface of graft at the level of renal hilum. The average of these two values was then determined to acquire the mean renal depth. Fixed depth used for calculation of GFR was 6 cm as specified by vendor. Renograms were processed separately using fixed depth and CT derived depth measurements. Region of interest (ROI) over renal allograft was assigned manually on the summed up images obtained from 1 to 3 minutes following injection. The semilunar background ROI was defined. The background corrected time-activity curve was generated and renal indices were calculated as per Gates algorithm in each patient separately for CT depth correction and fixed depth correction. Values are given as mean ± standard deviation. The association between Gates GFR and equation based GFR was assessed by multiple regression analysis. Whenever P value was found to be less than 0.05, it was considered to be significant.

On day 2, 185 MBq of DTPA was injected and venous blood sample for GFR estimation was collected from cubital region of 10 patients.

This study was not performed on same day as DTPA renogram as the dose injected for transplant renogram is higher as per standard recommendation. This higher dose of DTPA may affect the well counter used to count the radioactivity for SPSM. In view of clinical setting of renal transplant and risk of introducing infection, only 10 patients participated for SPSM procedure. GFR calculation was based on Russells method of estimation. Samples were drawn at 180 min after DTPA injection.

The blood samples were centrifuged at 1000 gyrations for 10 min to separate the red blood cells from the plasma.One ml of plasma was collected from each sample and standards were counted in an automatic gamma counter for 1 min. Decay of radioactivity was corrected.

^{99m}Tc-DTPA plasma clearance in our series was calculated using Russells equation as given below, GFR value was obtained in ml/min:

$$A \ln D/P + B$$

Where A = −0.278T + 119.1 + 2450/T, B = 2.886T − 1222.9 − 16820/T, D = total injected dose counts (counts per min, cpm), P = plasma activity (cpm/ml), T = sampling time (180 min).

Plasma samples were counted with appropriate standards and blanks for background in a well counter. The background counts were also subtracted.

RESULTS

Results were blinded. Two senior nuclear physicians interpreted the data individually. The depth of allograft placed was found to be 5.2 to 6.4 cm in our population (Figure 1).

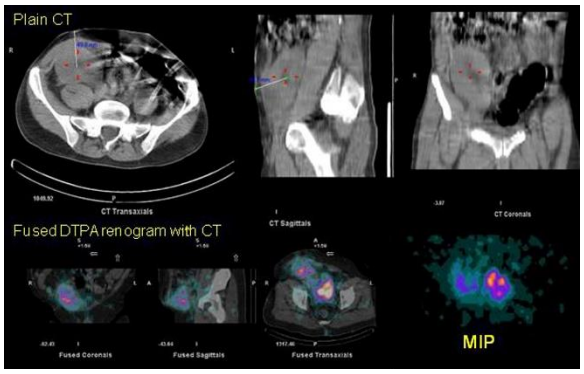

Fig 1. CT depth measurements of renal allograft in DTPA transplant renogram.

Our study with only male patients with no significant body weight difference, near normal creatinine values (by Jaffes method), same ethnicity, with standardization of DTPA renogram procedure (dosage, ROI drawing, and estimation of renal depth) shows good association with creatinine based equations. Karl Pearson coefficient of correlation and Paired sample t test analysed using SPSS version 15.0 (SPSS Inc., Chicago, IL) statistical software. All data were expressed as mean ± standard deviation (SD).

The performance of each method was determined by calculating the bias, precision, and accuracy as recommended by National Kidney Foundation Disease Outcomes Quality Initiative (K/DOQI) clinical practice guideline 2003. Bias was calculated by subtracting the measured GFR value from the estimated GFR. A negative bias actually reflects underestimation of GFR by that equation. Precision, a measure of the dispersion of the individual biases around the median or mean bias, was defined as the interquartile range (the difference between the 75th and 25th percentiles) of the median bias and as the SD of the mean bias. Accuracy, which reflects both bias and precision, was defined as the percentage of GFR estimates lying within 30% of the measured GFR values.

The analysis was repeated based on GFR cut point of 60 milliliters/minute per 1.73 m^2. Differences in equation bias and accuracy were assessed with a paired *t*-test or a McNemar test as appropriate. As all patients were of same gender, patient's age also contributed little effect on the estimation of renal depth.

CKD-EPI equation fared better than MDRD in patients with higher GFR values (> 60 ml/min/1.72 m^2. In our series we found MDRD equation was more reliable in patients with GFR <60 mL/min/1.73m^2. However while considering only creatinine based equations, no significant difference was observed in precision and accuracy between MDRD and CKD-EPI methods (10.4 versus 9.8 mL/min/1.73m^2, respectively). Accuracy was highest with depth corrected DTPA renogram (69.2%) than for fixed depth GFR (60 %, p ¼ 0.0012) in our series (Figure 2). The difference for the 30% accuracy reached the level of significance (p ¼ 0.0014, McNemar test), whereas the 10 and 50% accuracy did not (p ¼ 0.17 and p ¼ 0.06, respectively). Mean GFR obtained from SPSM was not different from CT depth corrected GFR estimation; ranges of both methods were also quite similar as shown in Table 1. There was good correlation between single plasma sampling method and CT depth corrected DTPA renogram method.

Table 1: GFR estimation obtained by different methods.

Methods of GFR estimation	Mean measured GFR (ml/min/1.73m^2)	Range
Fixed depth DTPA method	59.5	46.21 ± 16.30
CT depth corrected DTPA method	48.7	39.09 ± 12.14
MDRD equation (Modification of Diet in Renal Disease)	65.3	55.55 ± 11.48
CKD-EPI equation	69.1	65.04 ± 20.21
Single plasma sample method	46.5	38.01 ± 11.11

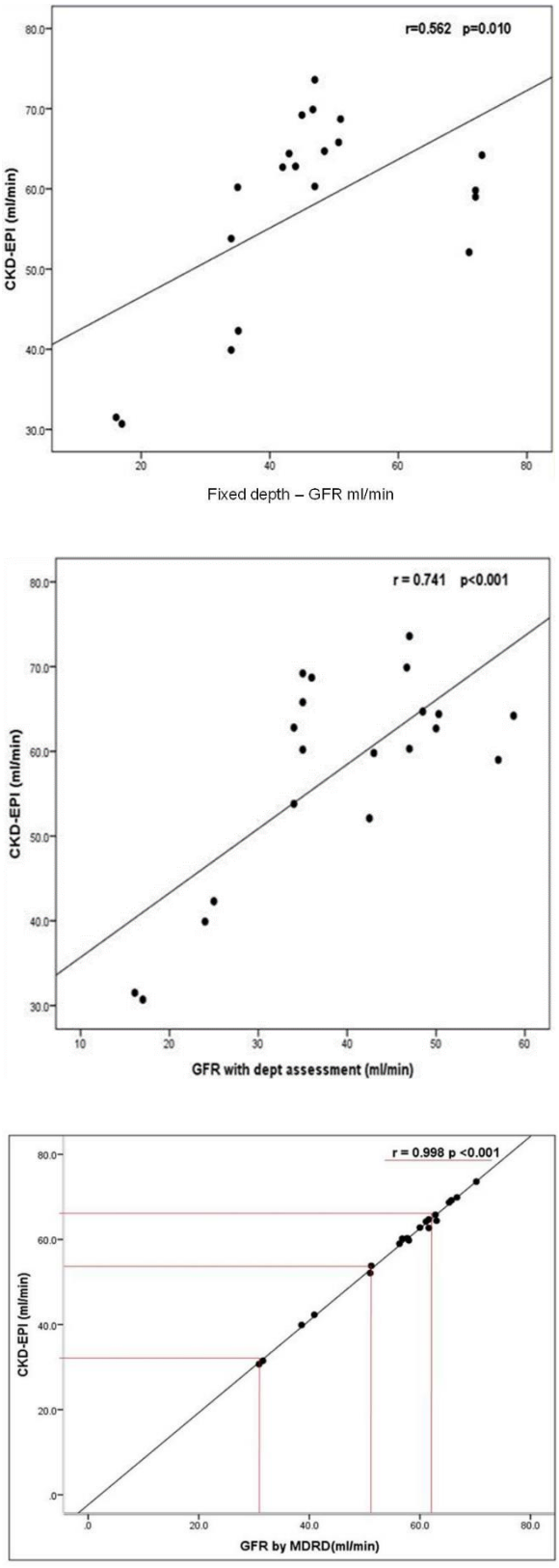

Fig 2. Correlation of GFR by CKD-EPI equation and fixed depth DTPA renogram method (above), correlation of GFR by CKD-EPI equation and depth corrected DTPA renogram method (middle), and GFR from MDRD and CKD-EPI equations.

DISCUSSION

Serum creatinine

Serum creatinine is the best known and most commonly used biochemical parameter for estimation of GFR, since it was first described as a GFR marker in 1937 [3]. It is well known that plasma creatinine estimation as a standalone test, can elicit a large intra individual variation of around 5.3% [4].This variation may lead to wrong interpretation of clinical results due to a large reference interval range. A patient with high plasma creatinine value due to deterioration in renal function may still have values within the normal reference range. In a post renal transplant setting it is imperative to avoid such fallacies and determine an accurate GFR to rule out early graft dysfunction. It has also been reported that variables like patients' age, gender, muscle mass, diet, and ethnicity can affect the eGFR values [5] .Thus a thin built male with renal dysfunction may exhibit a normal plasma creatinine level while e GFR is reduced; conversely a heavy built muscular male may show an abnormal creatinine value in spite of having normal renal function by eGFR method.

Other factors which can adversely affect the accuracy of serum creatinine levels include diet, like ingestion of meat, proteins, apart from sex, age, race, and muscle mass [6]. Particularly, in post renal transplant setting drugs like corticosteroids [7] trimethoprim [8] cephalosporin and aminoglycoside antibiotics, flucytosine, cisplatin, cimetidine inhibit tubular secretion of creatinine, thereby decreasing creatinine clearance and increasing serum creatinine without a change in GFR.

Because creatinine secretion is not predictable, the GFR can decrease to nearly half the normal value before the serum creatinine actually increases [9] with remarkable consequences in kidney transplant outcome, where subclinical progressive damage, such as calcineurin toxicity and rejection will not be early identified. Several studies in renal transplant setting demonstrated that the serum creatinine and GFR were barely correlated [10].

Creatinine based mathematical equations

There are numerous mathematical equations using these endogenous markers adjusted to other variables, mainly demographic, as an attempt to improve accuracy in eGFR. Each one of them has its own share of fallacies and needs to be adjusted according to the population under study.

a) Re expressed Cockcroft and Gault formula [10]

These equations are mainly re expressed Cockcroft and Gault formula (CG), Modification of Diet in Renal

Disease (MDRD) and (Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) equations. The CG was developed in 1973 using data from 249 men with creatinine clearance from approximately 30 to 130 mL/m^2. However it is not adjusted for body surface area. So CG is no longer recommended by the National kidney foundation for use because it has not been expressed using standardized creatinine values and it was found to overestimate kidney function. We have not incorporated this equation in our study.

b) MDRD formula

MDRD study group developed equations to predict GFR using demographic variables and clinical data. The 4 variable MDRD equation was developed in 1999 using data from 1628 patients with CKD with GFR from approximately 5 to 90 milliliters per minute per 1.73 m^2. It estimates GFR adjusted for body surface area and is more accurate than measured creatinine clearance from 24 hour urine collections or estimated by the CG formula. The old equation was re-expressed in 2005 for use with a standardized serum creatinine assay, which yields 5% lower values for serum creatinine concentration: 4, 6 MDRD formula has been found to perform reasonably well in transplant patients but was far from being an ideal estimation formula [11].

GFR = 175 x (Standardized S Cr) -1.154 x (age)-0.203 x (0.742 if female) x (1.210 if African American) GFR is expressed in mL/min/1.73 m^2, serum creatinine expressed in mg/dL, and age is expressed in years.

c) CKD-EPI equation

CKD-EPI is another similar equation which was developed in 2009 to estimate GFR from serum creatinine, age, sex, and race [12].

eGFR = 141 x min(S_{Cr}/κ, 1)$^{\alpha}$ x max(S_{Cr}/κ, 1)$^{-1.209}$ x 0.993^{Age} x 1.018 [if female] x 1.159 [if Black], where S_{Cr} (standardized serum creatinine) = mg/dL, κ = 0.7 (females) or 0.9 (males), α = -0.329 (females) or -0.411 (males), min = indicates the minimum of S_{Cr}/κ or 1,max = indicates the maximum of S_{Cr}/κ or 1 and age in years.

It is found to be more accurate than the MDRD Study equation, particularly in people with higher levels of GFR as reported by National kidney foundation manual. Based on the same four variables as the MDRD Study equation, instead uses a 2-slope “spline” to model the relationship between estimated GFR and serum creatinine, and a different relationship for age, sex and race. However there is no recommendation for its specific use in transplants.

The CKD-EPI equation was further used in Asians (Thai renal transplant recipients) and was reported to provide the best accuracy and precision [13], CKD-EPI was found to have the least bias compared with other eGFR equations [14]. Other studies showed that the CKD-EPI equation is as accurate as the MDRD equation in the subgroup with estimated GFR less than 60 mL/min/1.73 m^2 and substantially more accurate in the subgroup with estimated GFR greater than 60 mL/min/1.73 m^2.

DTPA renogram based GFR

The original recommended DTPA renogram protocol is based on Gates' method [15-17]. Although Gates method is popular due to its extreme simplicity and reproducibility, its accuracy was criticized as it did not take into account the attenuation correction and it is based on native (retroperitoneal) placed kidneys and is not meant for transplant kidney in anterior position.

Tonnesen formula in Gates method was introduced to correct for renal depth using ultrasound. However studies revealed that errors were introduced by the tissue attenuation correction while using the Tonnesen regression formula [18]. This was exaggerated in the patients with mal-positioned kidney or with renal transplant where the formula based estimate of the renal depth was obviously found invalid. Further studies were undertaken by replacing the Tonnesen formula by direct measurement of the kidney depth from lateral views, thus improving the accuracy of tissue attenuation correction of the renal uptake. Both ultrasonography based [19] and lateral renography based methods [20] for measuring renal depth have limitations. Other formulae based on CT derived native kidneys depth estimation include the Taylor, the Itoh, the T. itoh, the Li-qian, and the Inoue formula, which are beyond the scope of this study. All these formulae are region and population specific. The Taylor formula is derived from the Americans, the Itoh and the Inoue formulae are derived from the Japanese, while the Li-qian formula is based on Chinese population. Similarly Taylor, Li-qian, Inoue formulae are all based on the results in middle-aged and older patients.

CT derived renal depth measurement may be theoretically more accurate than those derived from ultrasound and CT based methods are considered to be more accurate than the other methods. Studies have shown that transplant graft sizes are similar to native kidneys; however, gradual increase of its dimensions can be seen over the first few weeks by up to 32% of the initial length by the fourth week [21]. The collecting system of a well-functioning transplant is often slightly dilated, presumably because of a combination of an increased volume of urine produced (because it is acting as the sole kidney) and loss of the ureters tonicity from denervation. Abdominal thickness was also introduced as a variable in renal depth estimation formulae such as the Taylor formula [22, 23] and there are reports suggesting that

abdominal thickness was more important than weight/height.

DTPA transplant renogram derived from planar imaging using Gates formula is unreliable as it uses a fixed depth measurement and is primarily meant for retroperitoneally placed native kidneys. GFR is a sensitive index and gets overtly influenced by body mass, dosage of DTPA injected, graft placement, depth of graft from skin surface.

GFR estimation by DTPA renogram is routinely performed using Gamma camera and calculated by computer based Gates algorithm. GFR measurement by Gates method is based on the percent total renal uptake of ^{99m}Tc-DTPA for 1 min from 2 to 3 min after the injection. Uptake of ^{99m}Tc-DTPA during the first few minutes is GFR times the integral of plasma concentration, $P(t)$ in this time interval. During the first few minutes after injection, $P(t)$ might be more determined by ^{99m}Tc-DTPA distribution than by renal clearance. Thus, the uptake of ^{99m}Tc-DTPA may reflect tracer distribution more than renal clearance. Although Gates GFR is a sensitive method, technical factors like 1) net injected activity, 2) kidney depth, 3) corrected kidney counts play a significant role in assessing kidney function. As per reports, a +/- 1 cm error in true kidney depth may cause a 16% difference in GFR in an adult. By standardizing DTPA renogram variables that can affect GFR estimation (dosage, drawing the region of interest, background) can be minimized.

Comparative performance of the MDRD and the Cockcroft-Gault formulae has been assessed in numerous studies with differing conclusions. A few studies have shown superiority of CKD-EPI equation over MDRD for renal assessment and vice versa. Others have used creatinine based equations with plasma sampling method of DTPA GFR to study the same. We have intentionally tried a simple camera based DTPA GFR method with and without depth correction. Generally, for native kidneys, the MDRD has been shown to perform somewhat better than Cockcroft-Gault in a majority of the studies, with less bias and a higher proportion of results in agreement with a radionuclide gold standard. A few reports have described that MDRD equation underestimates GFR in patients or volunteers with higher GFR values.

In renal transplantation all tested MDRD formulas showed a considerable better prediction of true GFR than the commonly used CG equation. In patients well preserved kidney function, MDRD equations reveal underestimation of GFR. We and others have shown this shortcoming also to hold true in transplant kidneys. CG is supposed to be faring well when serum creatinine is within the reference interval.

Pöge et al. [24] analysed the new CKD-EPI formula in comparison to the re-expressed MDRD equation in 170 stable patients after renal transplantation and concluded that it did not improve the estimation of GFR in Caucasian patients after renal transplantation. Our study was comparable to White et al. [25] who found a lower bias for the CKD-EPI equation in comparison to the re-expressed MDRD formula in transplants.

There were no differences with respect to precision or accuracy in the overall cohort. On the contrary, Stevens et al. [26] found a higher accuracy by using the CKD-EPI equation. Our study differs from others, as we have tried to compare the results with depth corrected DTPA GFR estimation to assess its superiority if any. There are not many studies using Gates GFR with depth correction versus creatinine based equations on GFR estimation.

In this study, we found that CT depth corrected GFR estimation with DTPA renogram has the highest accuracy and reliability with least bias when compared with creatinine based equations. There was good correlation between the gold standard single plasma sampling method and CT depth corrected DTPA renogram. Being a reproducible and easy to perform renal functional assessment, we recommend CT depth corrected GFR estimation for transplant recipients. Ours is the first study comparing these 4 methodologies with plasma sampling technique in transplant patients. More studies are needed to substantiate this statement in transplant setting. Taking into consideration creatinine based equations, CKD-EPI equations fares better. MDRD formula should be used with caution in post-transplant patients.

CONCLUSION

We conclude that CT depth corrected DTPA renogram provides an accurate, and reproducible GFR value in renal allograft recipients. Standardization of DTPA renogram procedure (dosage, ROI drawing, and estimation of renal depth) is a prerequisite for GFR estimation. Patient age has little effect on the estimation of renal depth. Based GFR assessment should be routinely used in renal transplants as it is not only sensitive but reproducible. Instead of using fixed depth values while computing Gates GFR in transplant recipients, CT derived depth measurements may be incorporated. This may be more reliable and accurate especially in asymptomatic transplant patients with stable creatinine values but with subtle renal dysfunction. ^{99m}Tc-DTPA based GFR estimation with depth correction is found to be a sensitive, reliable and accurate method in transplant recipients in our population. MDRD and CKD-EPI equation based GFR in our study shows overestimation in transplants even with stable creatinine values. Thus creatinine based methods have to be used with caution in transplant setting.

REFERENCES

1. National Kidney Foundation. K/DOQI clinical practice guidelines for bone metabolism and disease in chronic kidney disease. Am J Kidney Dis. 2003 Oct;42(4 Suppl 3):S1-201.
2. Taylor AT. Radionuclides in nephrourology, part 1: Radiopharmaceuticals, quality control, and quantitative indices. J Nucl Med. 2014 Apr;55(4):608-15.
3. Popper H, Mandel E. Filtrations and reabsorptions leitung in der nierenpathologie. Erg Inn Med Kinder 1937;53:685-95.
4. Desirable Biological Variation Database specifications. http://www.westgard.com/biodatabase1.htm (Accessed 15 November 2019).
5. Mula-Abed WA, Al Rasadi K, Al-Riyami D. Estimated glomerular filtration rate (eGFR): A serum creatinine-based test for the detection of chronic kidney disease and its impact on clinical practice. Oman Med J. 2012 Mar;27(2):108-13.
6. Santos J, Martins LS. Estimating glomerular filtration rate in kidney transplantation: Still searching for the best marker. World J Nephrol. 2015 Jul 6;4(3):345-53.
7. Horber FF, Scheidegger J, Frey FJ. Overestimation of renal function in glucocorticosteroid treated patients. Eur J Clin Pharmacol. 1985;28(5):537-41.
8. Berglund F, Killander J, Pompeius R. Effect of trimethoprim-sulfamethoxazole on the renal excretion of creatinine in man. J Urol. 1975 Dec;114(6):802-8.
9. National Kidney Foundation. K/DOQI clinical practice guidelines for chronic kidney disease: evaluation, classification, and stratification. Am J Kidney Dis. 2002;39:S1–266.
10. Botev R, Mallié JP, Couchoud C, Schück O, Fauvel JP, Wetzels JF, Lee N, De Santo NG, Cirillo M. Estimating glomerular filtration rate: Cockcroft-Gault and Modification of Diet in Renal Disease formulas compared to renal inulin clearance. Clin J Am Soc Nephrol. 2009 May;4(5):899-906.
11. Pöge U, Gerhardt T, Palmedo H, Klehr HU, Sauerbruch T, Woitas RP. MDRD equations for estimation of GFR in renal transplant recipients. Am J Transplant. 2005 Jun;5(6):1306-11.
12. Florkowski CM, Chew-Harris JS. Methods of Estimating GFR - Different Equations Including CKD-EPI. Clin Biochem Rev. 2011 May;32(2):75-9.
13. Townamchai N, Praditpornsilpa K, Chawatanarat T, Avihingsanon Y, Tiranathanagul K, Katavetin P, Susantitaphong P, Kanjanabuch T, Tungsanga K, Eiam-Ong S. The validation of estimated glomerular filtration rate (eGFR) equation for renal transplant recipients. Clin Nephrol. 2013 Mar;79(3):206-13.
14. Kamaruzaman L, Mohd R, Zaki FM, Hod R, Aziz AA. Estimating glomerular filtration rate in adult kidney transplant recipients in the Asian population. Saudi J Kidney Dis Transpl. 2019 May-Jun;30(3):587-596.
15. Gates GF. Glomerular filtration rate: estimation from fractional renal accumulation of 99mTc-DTPA (stannous). AJR Am J Roentgenol. 1982 Mar;138(3):565-70.
16. Gates GF. Split renal function testing using Tc-99m DTPA. A rapid technique for determining differential glomerular filtration. Clin Nucl Med. 1983 Sep;8(9):400-7.
17. Gates GF.Computation of glomerular filtration rate with technetium-99m-DTPA an: in-house computer program. J Nucl Med 1984;25:613- 6I8.
18. Tønnesen KH, Munck O, Hald T. Zum Winkel K, Mlaufox MD, Funck-Bretano JL. Influence on the radiorenogram of variation in skin to kidney distance and the clinical importance hereof. In: Zum Winkle K, Mllaufox MD, Funck-Bretano JL, Editors. Proceedings of the International Symposium on Radionuclides in Nephrourology. Stuttgart: Thieme;1974. p. 79–86.
19. Granerus G, Moonen M. Effects of extra-renal background subtraction and kidney depth correction in the measurement of GFR by gamma camera renography. Nucl Med Commun. 1991 Jun;12(6):519-27.
20. Maneval DC, Magill HL, Cypess AM, Rodman JH. Measurement of skin-to-kidney distance in children: implications for quantitative renography. J Nucl Med. 1990 Mar;31(3):287-91.
21. Lachance SL, Adamson D, Barry JM. Ultrasonically determined kidney transplant hypertrophy. J Urol. 1988 Mar;139(3):497-8.
22. Ma G, Shao M, Xu B, Tian J, Chen Y. Establish new formulas for the calculation of renal depth in both children and adults. Clin Nucl Med. 2015 Jul;40(7):e357-62.
23. Taylor A, Lewis C, Giacometti A, Hall EC, Barefield KP. Improved formulas for the estimation of renal depth in adults. J Nucl Med. 1993 Oct;34(10):1766-9.
24. Pöge U, Gerhardt T, Stoffel-Wagner B, Sauerbruch T, Woitas RP. Validation of the CKD-EPI formula in patients after renal transplantation. Nephrol Dial Transplant. 2011 Dec;26(12):4104-8.
25. White CA, Akbari A, Doucette S, Fergusson D, Knoll GA. Estimating glomerular filtration rate in kidney transplantation: is the new chronic kidney disease epidemiology collaboration equation any better? Clin Chem. 2010 Mar;56(3):474-7.
26. Stevens LA, Schmid CH, Greene T, Zhang YL, Beck GJ, Froissart M, Hamm LL, Lewis JB, Mauer M, Navis GJ, Steffes MW, Eggers PW, Coresh J, Levey AS. Comparative performance of the CKD Epidemiology Collaboration (CKD-EPI) and the Modification of Diet in Renal Disease (MDRD) Study equations for estimating GFR levels above 60 mL/min/1.73 m2. Am Am J Kidney Dis. 2010 Sep;56(3):486-95.