Received: 6 December 2016 | Accepted: 14 January 2017

DOI: 10.1002/jcla.22168

RESEARCH ARTICLE

WILEY

Evaluation and comparison of Abbott Jaffe and enzymatic creatinine methods: Could the old method meet the new requirements?

Tuncay Küme[1,2] | Barış Sağlam[3] | Cem Ergon[2,4] | Ali Rıza Sisman[1,2]

[1]Medical Biochemistry Department, Dokuz Eylül University Medical Faculty, Izmir, Turkey

[2]Central Laboratory, Dokuz Eylül University Hospital, Izmir, Turkey

[3]Biochemistry Laboratory, Biga State Hospital, Çanakkale, Turkey

[4]Medical Microbiology Department, Dokuz Eylül University Medical Faculty, Izmir, Turkey

Correspondence
Tuncay Küme, Medical Biochemistry Department, Dokuz Eylül University Medical Faculty, Izmir, Turkey.
Email: tuncay.kume@gmail.com

[Corrections added on February 24, 2017, after first online publication: An additional affiliation was added for Tuncay Küme and Ali Rıza Sisman and the affiliation of Cem Ergon was changed.]

Background: The aim of this study is to evaluate and compare the analytical performance characteristics of the two creatinine methods based on the Jaffe and enzymatic methods.

Methods: Two original creatinine methods, Jaffe and enzymatic, were evaluated on Architect c16000 automated analyzer via limit of detection (LOD) and limit of quantitation (LOQ), linearity, intra-assay and inter-assay precision, and comparability in serum and urine samples. The method comparison and bias estimation using patient samples according to CLSI guideline were performed on 230 serum and 141 urine samples by analyzing on the same auto-analyzer.

Results: The LODs were determined as 0.1 mg/dL for both serum methods and as 0.25 and 0.07 mg/dL for the Jaffe and the enzymatic urine method respectively. The LOQs were similar with 0.05 mg/dL value for both serum methods, and enzymatic urine method had a lower LOQ than Jaffe urine method, values at 0.5 and 2 mg/dL respectively. Both methods were linear up to 65 mg/dL for serum and 260 mg/dL for urine. The intra-assay and inter-assay precision data were under desirable levels in both methods. The higher correlations were determined between two methods in serum and urine (r=.9994, r=.9998 respectively). On the other hand, Jaffe method gave the higher creatinine results than enzymatic method, especially at the low concentrations in both serum and urine.

Conclusions: Both Jaffe and enzymatic methods were found to meet the analytical performance requirements in routine use. However, enzymatic method was found to have better performance in low creatinine levels.

KEYWORDS

creatinine, enzymatic, Jaffe, method comparison, method validation

1 | INTRODUCTION

Chronic Kidney Disease (CKD) is one of the essential public health problems worldwide.[1] Glomerular Filtration Rate (GFR) is the best index to evaluate the renal functions and determine the CKD.[2,3] The measurement of GFR is important for the accurate assessment of risk, drug-dose adjustment, diagnosis and staging of renal disease.[4] GFR is calculated from clearances of exogenous substances such as inulin, iohexol, iotalamat.[5–7] But, these methods have limited use in clinical settings because of the difficulty of urine collection procedure, cost, and risk of radiation exposure. These methods are only suitable for research, not for routine use.

 © 2017 Wiley Periodicals, Inc.

Serum and urine creatinine levels are the most common used tests to evaluate GFR and renal functions routinely.[8,9] These are good markers of GFR because of low intra-individual variations, endogenously presence of creatinine, and full filtration from glomerular and no tubuler reabsorption. But, there are some disadvantages such as it is affected by age, sex, race, muscle mass, diet, exercise, thyroid functions, and extra-renal elimination and tubular secretion.[10–13] Twenty four hours urine test is not recommended for GFR calculation because of urine collection errors, trouble to patients, incomplete bladder discharge and >25% of between-day variations of creatinine clearance.[14]

National Kidney Disease Education Program (NKDEP) Laboratory Working Group, recommends the estimation of glomerular filtration rate based on serum creatinine values, using the Modification of Diet in Renal Disease (MDRD) study and Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) equation.[15–18] Nephrologists prefer estimated GFR (e-GFR) of serum creatinine to creatinine clearance because of the change caused by age, sex, race, and wider reference ranges of serum creatinine and limitations of 24-hours creatinine clearance test.[19]

The methods used for creatinine measurement are chemical and enzymatic methods on automated analyzer, high-performance liquid chromatography (HPLC) and isotope dilution-mass spectrometry (IDMS). IDMS is a reference method of creatinine measurement, but it is not practical for routine and stat usage. Creatinine methods used in clinical laboratories are generally based on automated chemical or enzymatic methods. The most common method is the Jaffe-based creatinine-picrate forming in an alkaline medium.[20] Jaffe method is affected from picric acid concentration, pH, wavelength, temperature, and interferents. This method is not specific to creatinine, it is also affected by substances such as bilirubin, glucose, protein, aceto-acetate and cephalosporin. So, it is measured 15-25% higher then the actual value. Bilirubin among these interferent cause negative interference.[21] There is a method called compensated method where the error compensation of interference is corrected with factor compared IDMS method. But, compensation does not completely eliminate the error, because of the variations of interferents in patient samples. The use of the methods based on an enzymatic reaction could improve the specificity of the measurement because, in this case, it prevents the interference of the non-creatinine compounds. But the cost is a disadvantage for this method.

In 2006, NKDEP Laboratory Working Group reported standardization needs in serum/plasma creatinine measurements and collaborated with the International Federation of Clinical Chemistry and Laboratory Medicine (IFCC).[18] The main aim was more accurate analysis by decreasing inter-laboratory variations. Also, the Joint Committee for Traceability in Laboratory medicine (JCTLM) has been established with the aim to support worldwide traceability and standardization. NKDEP announced the recommendations for IDMS traceability and standardization of creatinine methods to: clinical laboratories, in vitro diagnostic manufacturers, proficiency testing (PT) or external quality assessment (EQA) providers, pharmacists, and authorized drug prescribers, National Metrology Institutes, reference laboratories, JCTLM organizational members and software vendors.

In our clinical laboratory, routine creatinine analysis is performed on automated analyzer based Jaffe method. In addition, we will plan to use enzymatic creatinine method on the same analyzer to meet the clinical requirements. In this study, we evaluated the analytical performance characteristics of the methods and compared the two creatinine methods based on Jaffe and enzymatic rate methods in serum and urine samples.

2 | MATERIALS AND METHODS

2.1 | Samples

Six different sample pools for precision studies were prepared at creatinine levels of 0.6, 1.6, 6.0 mg/dL for serum and 30, 60, 120 mg/dL for urine. The sample pools were stored for 20 days at −20°C until the time of analysis.

Serum and urine specimens were collected from 230 and 141 patients, respectively for whom a creatinine test was requested for routine analysis by Jaffe method. To perform comparison studies, left over samples from routine creatinine tests were used. No additional samples were collected, no medical-records reviewed or no contact with the patients were made, and no patient consent was obtained. The samples were analyzed on the same day. They were not stored.

2.2 | Instrument, reagents and other materials

Two original creatinine reagent kit based on different methodology (Creatinine (Jaffe), catalog no. 7D64-20 and Multigent Creatinine (Enzymatic), catalog no. 8L24-31) by using Architect c16000 automated analyzer (Abbott Diagnostics Inc, Park City, IL, USA) were performed. During the working period, the same quality control material for serum (Bio-Rad chemistry lypocheck, catalog no. L1 C310-5 and L2 C315-5) and for urine (Bio-Rad urine chemistry, catalog no. 316 and 377) and calibrator for Jaffe method (Multi-constituent calibrator, catalog no. 1E65) and for serum enzymatic method (Clin Chem calibrator, catalog no. 6K30-10) and calibration factor for urine enzymatic method provided by the manufacturer were included in the study.

2.3 | Creatinine methods

Two automated creatinine methods based on Jaffe and enzymatic principle were performed. Jaffe creatinine method is based on alkaline picrate. At an alkaline pH, creatinine in the sample reacts with picrate to form a creatinine-picrate complex. The rate of increase in the absorbance at 500 nm because of the formation of this complex is directly proportional to the concentration of creatinine in the sample. The other creatinine method is based on enzymatic principle. Creatinine in the sample is hydrolyzed by creatininase to creatine. Creatine is in turn hydrolyzed by creatinase to sarcosine and urea. Sarcosine from this reaction is oxidized by sarcosine oxidase to glycine and formaldehyde, with the concomitant production of hydrogen peroxide. The hydrogen peroxide reacts with 4-aminoantipyrine and N-ethyl-N-sulfopropyl-m-toluidine in the presence of peroxidase

TABLE 1 Summary of method parameters

	Serum		Urine	
	Jaffe	Enzymatic	Jaffe	Enzymatic
Reaction type	Rate up	End up	Rate up	End up
Wavelength (nm) (Primary/Secondary)	500/572	548/700	500/572	548/700
Read times (×18 seconds)	18-22	31-33	18-22	31-33
Sample blank times (×18 seconds)	-	13-15	-	13-15
Volumes (S/R1/R2) (μL)	9.6/200/48	3.6/160/53	8.0/200/48	3.6/160/53
Sample dilution rate	1: 1	1: 1	1: 20	1: 10
Calibration method	Linear	Linear	Linear (use serum curve)	Use Cal Factor
Detection Range (mg/dL)	0.2-38.70	0.25-40	0.21-37.85	0.10-40

S: Sample; R1: Reagent1; R2: Reagent 2.

to yield a quinoneimine dye. The resulting change in absorbance at 548 nm is proportional to the creatinine concentration in the sample.

The Jaffe creatinine method has a limit of quantitation (LOQ) of 0.2 mg/dL, a limit of linearity (LOL) of 38.7 mg/dL and an extended measuring range of 0.2-387 mg/dL (with auto rerun), according to the manufacturer. The enzymatic creatinine method is a LOQ of 0.1 mg/dL, a LOL of 40 mg/dL and extended measuring range of 0.1-400 mg/dL (with auto rerun), according to the manufacturer. The two methods are standardized according to IDMS traceable National Institute of Standards and Technology Standard Reference Material (NIST SRM) 967 for serum application and NIST SRM 914 for urine application following the NKDEP, IFCC and European Communities Confederation of Clinical Chemistry and Laboratory Medicine (EC4) recommendations promoting the use of commutable reference material.

The method parameters for serum and urine methods applied on the analyzer are summarized in Table 1.

2.4 | Analytical performance studies

2.4.1 | Limit of Detection

We determined the LOD of each method by analyzing a zero calibrator 20 times and calculating a 3 SD limit.

2.4.2 | Limit of Quantitation

We determined the coefficient of variations (CVs) for the five sample pools that have a different creatinine concentration from each other. The LOQs are defined as the minimum concentration at which CV is lower than 10%.

2.4.3 | Precision

We determined intra-assay coefficient of variations (CVs) on the same day by measuring one sample 20 times in one analytical run. Inter-assay CVs were determined on 20 consecutive days on the basis of a single calibration.

2.4.4 | Linearity

Samples to test linearity were prepared from two serum and two urine pools. The low pool was prepared by mixing patient samples with creatinine concentrations of 0.1 mg/dL for serum and 0.25 mg/dL for urine. The high pool was prepared by mixing patient samples with creatinine concentrations of 65 mg/dL for serum and 260 mg/dL for urine. The high concentrated pool was diluted with the low concentrated pool to obtain the following final percentages of high pool: 100%, 90%, 80%, 40%, 20%, and 0%. Samples were analyzed in duplicate in one analytical run.

2.5 | Method comparison studies

Method comparison tests were performed according to the Clinical and Laboratory Standards Institute (CLSI) protocol.[22] Tests were conducted on 10 different days with 230 patient serum and 141 urine samples. The creatinine concentrations of the samples were measured by Jaffe and enzymatic methods on the automated analyzer within 2 hours.

The serum samples used for the method comparison study ranged from 0.22 mg/dL to 7.68 mg/dL and were selected as: 30% of total samples below 0.59 mg/dL, 40% at 0.6-1.6 mg/dL, and 30% of samples >1.6 mg/L. The urine samples ranged from 0.60 mg/dL to 331 mg/dL and were selected as: 36% of total samples below 29 mg/dL, 28% at 30-59 mg/dL, and 50% of samples >60 mg/dL.

2.6 | Statistical analyses

The MedCalc for Windows statistical package (MedCalc Software, Ostend, Belgium) was used to perform a descriptive statistical analysis. The slope, intercept, Sy|x, and *r* were estimated using Passing-Bablok regression analysis. Agreement between the methods was

TABLE 2 Summary of intra-assay (A) and inter-assay (B) precision data

		Serum				Urine			
		Jaffe		Enzymatic		Jaffe		Enzymatic	
Pool	N	Mean	CV%	Mean	CV%	Mean	CV%	Mean	CV%
(A)									
1	20	0.64	1.45	0.62	0.72	32.69	1.52	30.95	0.78
2	20	1.67	1.03	1.62	0.74	62.01	1.07	60.92	0.73
3	20	6.60	0.50	6.41	0.34	127.00	0.80	124.83	0.41
(B)									
1	20	0.64	2.65	0.60	2.55	31.83	2.14	30.59	2.28
2	20	1.66	2.53	1.60	1.65	60.78	2.08	59.25	2.10
3	20	6.46	1.74	6.27	1.02	124.24	1.97	123.64	1.65

assessed visually using a Bland-Altman plot and the limits of agreement were also determined.

3 | RESULTS

The LODs for serum creatinine methods were defined as 0.01 mg/dL for both Jaffe and enzymatic methods. The LODs for urine creatinine methods were determined 0.25 mg/dL and 0.07 mg/dL for the Jaffe and the enzymatic method, respectively.

The intra-assay and inter-assay precision data are summarized in Table 2A,B. All precision data were under desirable levels in both methods.

The LOQs were determined as the minimum concentrations at which CV were below 10%. The LOQs for serum enzymatic and Jaffe creatinine methods were the same, 0.05 mg/dL (Figure 1A). The urine enzymatic method had a lower LOQ than urine Jaffe method, with 0.5 and 2 mg/dL values, respectively (Figure 1B).

The linearity data is presented in Figures 2A-D. Both serum methods were linear up to 65 mg/dL and both urine methods were linear up to 260 mg/dL.

The patient sample-based method comparison data is presented in Figure 3A,B. The higher correlations were determined between enzymatic and Jaffe method in serum and urine (r=.9994, r=.9998, respectively). *X*-axis represents enzymatic method, and *Y*-axis represents Jaffe method in regression analysis. Passing-Bablok regression analysis gave a slope of 0.971448 and an intercept of 0.0486546 for serum methods, and a slope of 0.996702 and an intercept of 0.986235 for urine methods. The Bland-Altman analysis gave a mean difference of 4.2% and 2.8% between the two methods for serum and urine, respectively, as shown in Figure 4A,B. On the other hand, Jaffe method gave higher results than enzymatic method, especially at the low concentrations in both serum and urine. The difference between the two methods in serum creatinine analysis at the medical decision points of 0.6, 1,6 and 6.0 mg/L were 7.03%, 0.85%, and −1.86% respectively.

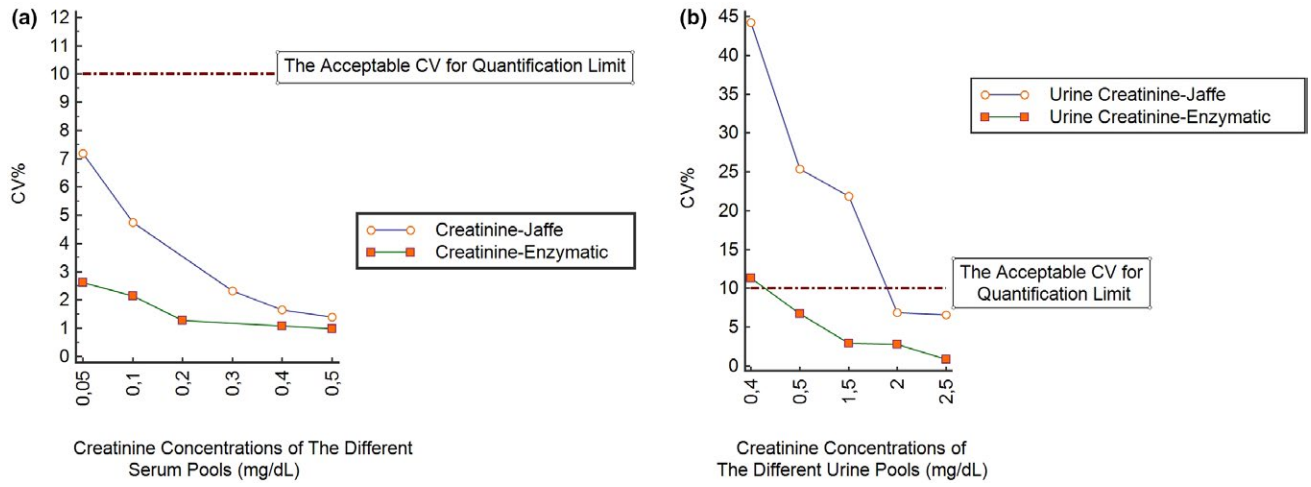


FIGURE 1 The limits of quantification for serum (A) and for urine (B) Jaffe and Enzymatic creatinine methods

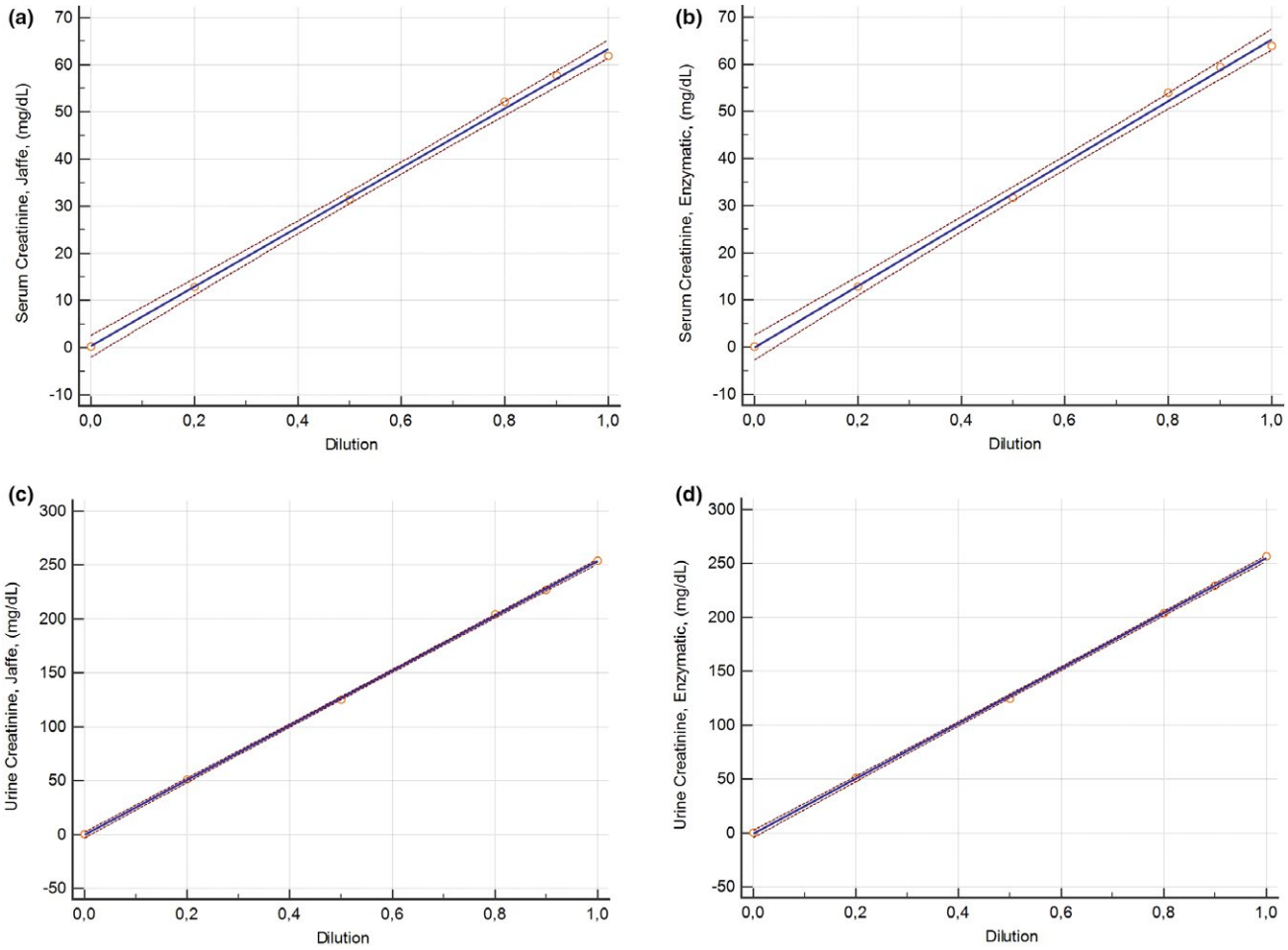


FIGURE 2 The linearity for serum Jaffe method (A) (*r*=.9992), serum enzymatic method (B) (*r*=.9991), for urine Jaffe method (C) (*r*=.9999), urine enzymatic method (D) (*r*=.9999)

4 | DISCUSSION

GFR is the best indicator of the renal functions.[8,9] There are some reference methods to determine GFR, like inulin clearance and radiological methods. However, they are not suitable for routine analysis because of some difficulties in practice, like higher price and risk of radiation. Serum and urine creatinine levels are used to determine GFR. Recently, nephrologists offer to use estimated GFR instead of 24-hours creatinine clearance or only serum creatinine levels.[23] Hence, nowadays, most clinical laboratories give e-GFR results automatically calculated by laboratory information systems in addition to serum creatinine results.[24,25] With the increasing usage of e-GFR, questioning of analytical performance of creatinine methods started.[26,27] So, a worldwide standardization program for creatinine methods were started by NKDEP and IFCC. NKDEP also recommended that manufacturers should improve the analytical performance of their creatinine methods and clinical laboratories should increase the effective use of creatinine testing.[18]

Jaffe reaction is the most frequently used creatinine methods in the clinical laboratories, but it is affected by some non-creatinine chromogens. The other method for routine creatinine analysis is the enzymatic method. However, its usage is limited to point of care testing and dry chemistry, because it is 10-folds more expensive than Jaffe method. In this study, we compared the analytical performance and the patient results produced by both Jaffe and enzymatic creatinine methods dedicated for Abbott Architect analyzer.

LODs were the same in both serum creatinine methods, but enzymatic method had a lower LOD than Jaffe in urine. These lower limits could meet the current accepted analytical requirements. On the other hand, LOQ generally accepted as the minimum concentration where CV is lower than <10% is more important than LOD in clinical laboratories.

Both the two serum methods had a CV<10% at concentration of 0.05 mg/dL that was the minimum test point in this study. As seen Figure 1A, the enzymatic method had a better CV than Jaffe. Urine enzymatic method had a lower LOQ than Jaffe, but nonetheless Jaffe had a LOQ that meets the requirements for routine analysis (Figure 1B).

The linearity tests were carried out by dilutions of high concentrated pools with low concentrated pools. We found that both methods were linear up to 65 mg/dL and up to 260 mg/dL in serum and urine respectively (Figure 2A-D). These upper measurement points were enough for routine analysis.

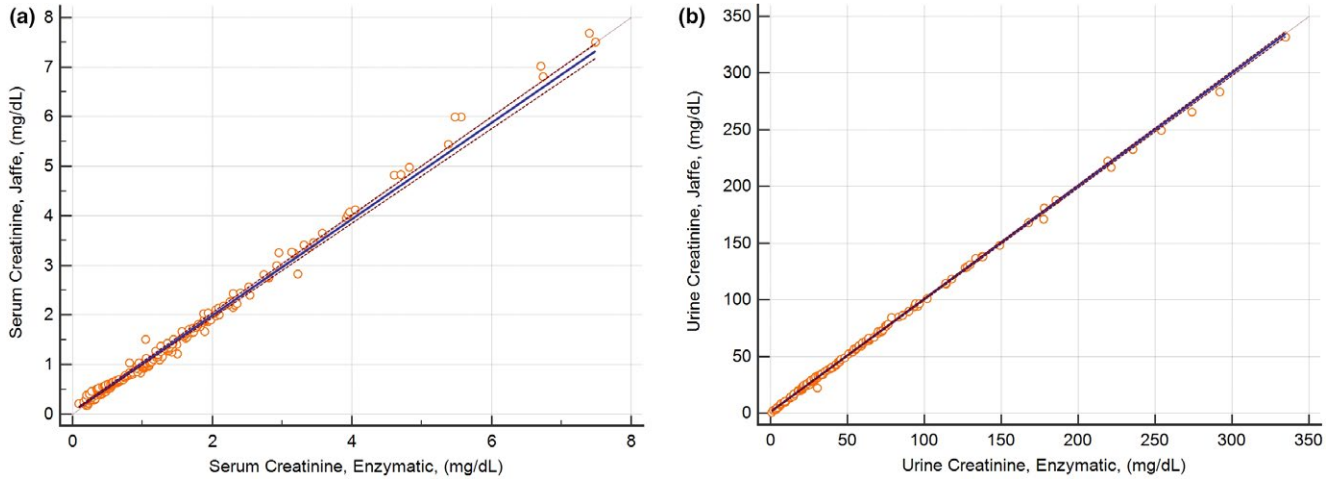


FIGURE 3 The patient sample-based comparison between serum (A) Jaffe and Enzymatic methods. (*y*=0.0486546+0.971448 *x*, Sy/*x*=0.08285, *r*=.994) and Urine (B) Jaffe and Enzymatic methods. (*y*=0.986235+0.996702 *x*, Sy/*x*=1.3327, *r*=.998)

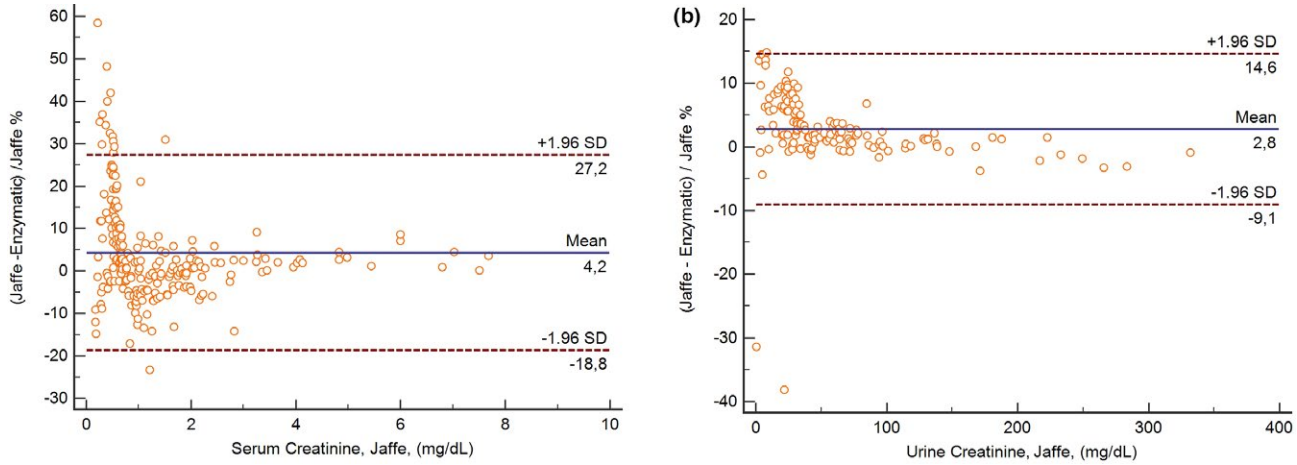


FIGURE 4 Bland-Altman plot for the serum (A) and urine (B) creatinine methods

We found that both methods had a good precision at the three different concentrations of serum and urine pools as shown in Table 2A,B, but enzymatic method had better precisions than Jaffe. The maximum intra-assay CVs for serum and urine were 1.45% and <1.52%, and the maximum inter-assay CVs for serum and urine were <2.65% and <2.28%. In general, it is accepted that maximum acceptable CV is less than one-half of intra-individual variations.[28] Intra-individual CV for serum creatinine obtained from the biological variation study is 5.95%, so desirable CV is <2.98%.[29] We found that intra-assay and inter-assay CVs were lower than desirable CVs in both serum and urine methods.

The differences between the results of enzymatic and Jaffe methods were determined by 230 serum and 141 urine sample according to CLSI guideline, EP09-A2-IR.[22] The higher correlations were defined by both of the methods in serum and in urine (*r*>.999) (Figure 3A,B). As seen in the Bland-Altman plot, Jaffe method gave the higher results than the enzymatic method, with an average of 4.2% and of 2.8%, in serum and in urine respectively (Figure 4A,B). As Bland-Altman plot is assessed visually, it is seen that the difference between the two method in serum are higher at concentrations of <1.0 mg/dL. The biases between the two methods in serum at concentrations of 0.6, 1.6, and 6.0 mg/dL were 7.03%, 0.85% and −1.86%, respectively. However, the Jaffe method in serum gave an average higher result of 7.03% than the enzymatic method at the concentration of 0.6 mg/dL, which is at the lower part of reference interval in men and women. The Jaffe method's mean higher result of 7.03% does not meet the desirable bias of 3.96%.[30] We calculated the total analytical error of the serum Jaffe as 11.4% at concentration of 0.6 mg/dL by using "Total Allowable Error (TEa)=bias%+1.65 CV%" formula. This TEa meets minimum allowable TEa (11.4%), but does not meet the desirable TEa (8.87%).[18] These results justify NKDEP's suggestions that offer the manufacturer to improve the analytical performance of their serum creatinine methods especially at concentrations of <1.0 mg/dL. Considering inter-assay CVs of serum Jaffe method are <2.65%, which is lower than desirable CVs,[18] it can be concluded that the biggest part of TEa is sourced from bias rather than CV.

Manufacturers adjust their method to IDMS to make a compensation of bias sourced from mainly non-creatinine chromogens, but it is obvious

that compensation cannot fix the issue completely as considered every sample has a different interferent. The relatively higher bias of serum Jaffe method at lower creatinine concentrations may cause to overestimation of GFR especially in children, elderly and during pregnancy.

For the true estimation of GFR, clinical laboratories should use IDMS traceable creatinine methods. It is reported that the non-traceable methods by IDMS, give a higher result of 10-30% than IDMS traceable methods.[31] Since both methods we compared in this study are traceable by IDMS, it may be concluded that the adjustment of calibrators only to IDMS cannot solve the bias problem exactly, especially in low creatinine concentrations. The creatinine concentrations of manufacturer's calibrators are generally at the upper part of reference range or higher than these levels.[32] However, relationship between concentration and absorbance at higher calibrator concentrations may not represent to those of lower calibrator concentrations. This problem could be overcome partially by means of using the multipoint calibration, especially including the calibrators with low creatinine concentrations. In a study comparing the inter-laboratory creatinine results, authors reported that there are important differences among laboratories in respect to the slope and intercept obtained from regression analysis.[32] Thus, manufacturers should consider the intercept and slope together, while adjusting their calibrator values to IDMS, and correcting patient results via application program on their analyzers.

The other GFR marker, cystatin C, has been intensively investigated in the last decade. In many research, it is reported that serum cystatin C has some superiorities against serum creatinine in assessment of GFR: being not affected by length, mass, diet, age and sex, and constant production rate and constant serum levels after 1 year old. However, there are some disadvantages of cystatin C like lower analytical performance, higher intra-individual variations and higher price (about 12-fold) then serum creatinine assays and there is no international standardization for cystatin C.[33–37] In addition, more studies are needed to define non-GFR determinant of cystatin C. Briefly, all existing data show that using cystatin C combine with serum creatinine will improve the accurate estimation of GFR.[38]

There are limitations in our study as we did not investigate the effect of interferance and different clinical conditions.

By this assessment with method evaluation and comparison data, both Jaffe and enzymatic methods were found to meet the analytical performance requirements for routine use. However, enzymatic method was found to have better performance in low creatine levels. Jaffe method was found 7% higher in the lower limit of reference ranges. If bias of the Jaffe method can be decreased to the desired level by manufacturers, this method will be used more safely in routine. In addition, since being ten-fold cheaper then enzymatic method, Jaffe method will remain as an important choice of clinical laboratories in the future.

REFERENCES

1. Shemesh O, Golbetz H, Kriss JP, Myers BD. Limitations of creatinine as a filtration marker in glomerulopathic patients. *Kidney Int*. 1985;28:830–838.
2. Laterza OF, Price CP, Scott MG. Cystatin C: an improved estimator of glomerular filtration rate? *Clin Chem*. 2002;48:699–707.
3. Vassalotti JA, Stevens LA, Levey AS. Testing for chronic kidney disease: a position statement from the National Kidney Foundation. *Am J Kidney Dis*. 2007;50:169–180.
4. Stevens LA, Coresh J, Greene T, Levey AS. Assessing kidney function–measured and estimated glomerular filtration rate. *N Engl J Med*. 2006;354:2473–2483.
5. Levey AS, Greene T, Schluchter MD, et al. Glomerular filtration rate measurements in clinical trials. Modification of Diet in Renal Disease Study Group and the Diabetes Control and Complications Trial Research Group. *J Am Soc Nephrol*. 1993;4:1159–1171.
6. Perrone RD, Steinman TI, Beck GJ, et al. Utility of radioisotopic filtration markers in chronic renal insufficiency: simultaneous comparison of 125I-iothalamate, 169Yb-DTPA, 99mTc-DTPA, and inulin. The Modification of Diet in Renal Disease Study. *Am J Kidney Dis*. 1990;16:224–235.
7. Stevens LA, Levey AS. Measured GFR as a confirmatory test for estimated GFR. *J Am Soc Nephrol*. 2009;20:2305–2313.
8. Narayanan S, Appleton HD. Creatinine: a review. *Clin Chem*. 1980;26:1119–1126.
9. Perrone RD, Madias NE, Levey AS. Serum creatinine as an index of renal function: new insights into old concepts. *Clin Chem*. 1992;38:1933–1953.
10. Elgadi A, Verbovszki P, Marcus C, Berg UB. Long-term effects of primary hypothyroidism on renal function in children. *J Pediatr*. 2008;152:860–864.
11. James GD, Sealey JE, Alderman M, et al. A longitudinal study of urinary creatinine and creatinine clearance in normal subjects. Race, sex, and age differences. *Am J Hypertens*. 1988;1:124–131.
12. Karawajczyk M, Ramklint M, Larsson A. Reduced cystatin C-estimated GFR and increased creatinine-estimated GFR in comparison with iohexol-estimated GFR in a hyperthyroid patient: a case report. *J Med Case Rep*. 2008;2:66.
13. Vargas F, Moreno JM, Rodriguez-Gomez I, et al. Vascular and renal function in experimental thyroid disorders. *Eur J Endocrinol*. 2006;154:197–212.
14. Goldberg TH, Finkelstein MS. Difficulties in estimating glomerular filtration rate in the elderly. *Arch Intern Med*. 1987;147:1430–1433.
15. Becker BN, Vassalotti JA. A software upgrade: CKD testing in 2010. *Am J Kidney Dis*. 2010;55:8–10.
16. Levey AS, Coresh J, Greene T, et al. Expressing the Modification of Diet in Renal Disease Study equation for estimating glomerular filtration rate with standardized serum creatinine values. *Clin Chem*. 2007;53:766–772.
17. Levey AS, Stevens LA. Estimating GFR using the CKD Epidemiology Collaboration (CKD-EPI) creatinine equation: more accurate GFR estimates, lower CKD prevalence estimates, and better risk predictions. *Am J Kidney Dis*. 2010;55:622–627.
18. Myers GL, Miller WG, Coresh J, et al. Recommendations for improving serum creatinine measurement: a report from the Laboratory Working Group of the National Kidney Disease Education Program. *Clin Chem*. 2006;52:5–18.
19. National Kidney F. K/DOQI clinical practice guidelines for chronic kidney disease: evaluation, classification, and stratification. *Am J Kidney Dis*. 2002;39(2 Suppl 1):S1–S266.
20. Jaffe M. Ueber den Niederschlag, welchen Pikrinsäure in normalem Harn erzeugt und über eine neue Reaction des Kreatinins. *ZPhysiolChem*. 1886;10:391–400.
21. Peake M, Whiting M. Measurement of serum creatinine–current status and future goals. *Clin Biochem Rev*. 2006;27:173–184.
22. Institute CLS. *Method Comparison and Bias Estimation Using Patient. Samples; Approved Guideline*. Second Edition (Interim Revision) (EP09-A2-IR). Wayne, PA: Clinical and Laboratory Standards Institute; 2010.

23. Levey AS, Stevens LA, Hostetter T. Automatic reporting of estimated glomerular filtration rate–just what the doctor ordered. *Clin Chem*. 2006;52:2188–2193.
24. Miller WG. Estimating glomerular filtration rate. *Clin Chem Lab Med*. 2009;47:1017–1019.
25. Narva AS. Assessment of kidney function for drug dosing. *Clin Chem*. 2009;55:1609–1611.
26. Coresh J, Astor BC, McQuillan G, et al. Calibration and random variation of the serum creatinine assay as critical elements of using equations to estimate glomerular filtration rate. *Am J Kidney Dis*. 2002;39:920–929.
27. Vickery S, Stevens PE, Dalton RN, van Lente F, Lamb EJ. Does the ID-MS traceable MDRD equation work and is it suitable for use with compensated Jaffe and enzymatic creatinine assays? *Nephrol Dial Transplant*. 2006;21:2439–2445.
28. Cotlove E, Harris EK, Williams GZ. Biological and analytic components of variation in long-term studies of serum constituents in normal subjects. 3. Physiological and medical implications. *Clin Chem*. 1970;16:1028–1032.
29. Ricos C, Alvarez V, Cava F, et al. Current databases on biological variation: pros, cons and progress. *Scand J Clin Lab Invest*. 1999;59:491–500.
30. Westgard QC. Desirable Biological Variation Database specifications. https://www.westgard.com/biodatabase1.htm. Accessed November 30, 2016.
31. Delanghe JR, Cobbaert C, Harmoinen A, Jansen R, Laitinen P, Panteghini M. Focusing on the clinical impact of standardization of creatinine measurements: a report by the EFCC Working Group on Creatinine Standardization. *Clin Chem Lab Med*. 2011;49:977–982.
32. Joffe M, Hsu CY, Feldman HI, Weir M, Landis JR, Hamm LL, Chronic Renal Insufficiency Cohort Study G. Variability of creatinine measurements in clinical laboratories: results from the CRIC study. *Am J Nephrol*. 2010;31:426–434.
33. Bargnoux AS, Perrin M, Garrigue V, et al. Analytical performances of cystatin C turbidimetric assay: which impact on accuracy of glomerular filtration rate estimation in renal transplantation? *Clin Chem Lab Med*. 2011;50:133–138.
34. Grubb A, Lofberg H. Human gamma-trace, a basic microprotein: amino acid sequence and presence in the adenohypophysis. *Proc Natl Acad Sci USA*. 1982;79:3024–3027.
35. Newman DJ. Cystatin C. *Ann Clin Biochem*. 2002;39(Pt 2):89–104.
36. Reinhard M, Erlandsen EJ, Randers E. Biological variation of cystatin C and creatinine. *Scand J Clin Lab Invest*. 2009;69:831–836.
37. Tenstad O, Roald AB, Grubb A, Aukland K. Renal handling of radiolabelled human cystatin C in the rat. *Scand J Clin Lab Invest*. 1996;56:409–414.
38. Shlipak MG, Matsushita K, Arnlov J, et al. Cystatin C versus creatinine in determining risk based on kidney function. *N Engl J Med*. 2013;369:932–943.

How to cite this article: Küme T, Sağlam B, Ergon C, Sisman AR. Evaluation and comparison of Abbott Jaffe and enzymatic creatinine methods: Could the old method meet the new requirements? *J Clin Lab Anal*. 2018;32:e22168. https://doi.org/10.1002/jcla.22168