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Original Paper

Comparison of the Estimated Glomerular Filtration Rate (eGFR) in Diabetic Patients, Non-Diabetic Patients and Living Kidney Donors

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Key Words
Inulin clearance • Estimated glomerular filtration rate • Diabetics Non-diabetics • Living kidney donor

Abstract
Background/Aims: We have reported that the eGFR overestimates renal function when glycemic control is poor. It has been reported that eGFR calculated by serum creatinine underestimates GFR in living kidney donors. We compared the utility of the eGFR in diabetic patients, non-diabetic patients and living kidney donors. Forty diabetic patients, 40 non-diabetic patients, and 40 living kidney donors were enrolled. ***Methods:*** GFR was measured by inulin clearance (C_{in}). eGFR was calculated based on serum creatinine ($eGFR_{cr}$) or serum cystatin C ($eGFR_{cys}$). We compared the agreements between each of the eGFR and C_{in} in each group. ***Results:*** There were significant and positive correlations between each eGFR and C_{in} in diabetic patients and non-diabetic patients. However, the intraclass correlation coefficients (ICC) between each eGFR and C_{in} in diabetic patients (ICC: $eGFR_{cr}$ 0.699, $eGFR_{cys}$ 0.604) were weaker than those in non-diabetic patients (ICC: $eGFR_{cr}$ 0.865, $eGFR_{cys}$ 0.803). The correlation coefficients between each eGFR and C_{in} ($eGFR_{cr}$; r = 0.422, p = 0.0067 and $eGFR_{cys}$; r = 0.358, p = 0.0522) in living kidney donors were significantly weaker than those in non-diabetic patients. The ICCs between each eGFR and C_{in} (ICC: $eGFR_{cr}$ 0.340, $eGFR_{cys}$ 0.345) in living kidney donors were significantly weaker than those in non-diabetic patients. ***Conclusions:*** Based on C_{in}, eGFR was accurate in non-diabetic patients. However, eGFR was inaccurate in living kidney donors and relatively inaccurate in diabetic patients.

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Introduction

With the continuing increase in the number of patients with end-stage renal disease (ESRD), accurate evaluation of renal function is necessary for the early diagnosis and strict control of renal dysfunction. In addition to microalbuminuria or proteinuria, evaluation of the glomerular filtration rate (GFR) by a creatinine-based formula is generally believed to provide a clinically useful index for the assessment of the progression of renal dysfunction and cardiovascular risk in chronic kidney disease [1, 2]. Although serum creatinine is widely used to estimate GFR, serum creatinine can be affected by muscle mass, gender, and age. As cystatin C is not affected by muscle mass, gender or age, serum cystatin C levels and equations that estimate GFR based on serum cystatin C have recently been proposed as better markers of GFR [3-6]. Meanwhile, the gold standard in the determining GFR is the measurement of inulin clearance (C_{in}). Therefore, the Japanese Society of Nephrology issued a new equation for estimating the glomerular filtration rate (eGFR) using C_{in} measurements in 763 Japanese subjects [7].

We previously demonstrated a significant decrease of serum creatinine in anuric diabetic hemodialysis patients compared with their non-diabetic counterparts [8], which was due to a reduction in the amount of creatinine in the muscle mass in diabetic hemodialysis patients [8]. Further, we demonstrated that poor glycemic control was a major factor in the overestimation of glomerular filtration rate (GFR) in diabetic patients [9, 10].

Horio [11] and Kakuta [12] et al. reported that eGFR underestimated the GFR in living kidney donors, when calculated using serum creatinine. However, the factors relevant to the underestimation of GFR in living kidney donors remained unknown.

To date, there has been no data available regarding a comparison of the utility of each eGFR measure, *i.e.,* eGFR based on serum creatinine ($eGFR_{cr}$) and serum cystatin C ($eGFR_{cys}$), in diabetic patients, non-diabetic patients and living kidney donors. Thus, in the present study, we evaluated the intraclass correlation coefficients between each eGFR calculation and C_{in} in diabetic patients, non-diabetic patients and living kidney donors.

Materials and Methods

Subjects

The study protocol was approved by the Ethics Committee of Osaka City University Graduate School of Medicine (#1444), Osaka, Japan, and the study was performed between January 2009 and March 2015. Subjects were consecutively enrolled in the present study, after obtaining written informed consent from each patient. The design was a single-center, randomized study that was conducted at Osaka City University Hospital. One hundred and twenty subjects (age 56.6 ± 15.4 years; 49 males and 71 females; 40 diabetic patients, 40 non-diabetic patients and 40 living kidney donors) were enrolled. The diagnosis of diabetes mellitus was based on a history of diabetes or criteria according to the Report of the Expert Committee on the Diagnosis and Classification of Diabetes Mellitus [13]. The enrolled living kidney donors were planned to provide a kidney for transplantation.

Assessment of renal function by eGFR based on serum creatinine and serum cystatin C

Serum creatinine was measured using enzymatic method [14, 15]. Serum cystatin C was measured using a colloidal gold immunoassay (Alfresa Pharma) [3, 15].

To develop an accurate eGFR estimation equation for the Japanese population, the Japanese Society of Nephrology launched a specific eGFR formula based on serum creatinine, with the simultaneous measurement of C_{in} in 763 Japanese subjects, which was obtained by cooperation of nationwide nephrologists from December 2006 to July 2007, as described below [7]:

$eGFR_{cr}$ (mL/min/1.73 m^2)=194 × $Cr^{-1.094}$ × $Age^{-0.287}$ (If female × 0.739)

Recently, the Japanese Society of Nephrology developed glomerular filtration rate (GFR)-estimating equations based on serum cystatin C ($eGFR_{cys}$) [15].

$eGFR_{cys}$ (mL/min/1.73 m^2)={104 × $CysC^{-1.019}$ × 0.996^{age} × 0.929 (if female)}−8. In the present study, cystatin C was measured in 101 patients, and $eGFR_{cys}$ was calculated in these patients.

Table 1. Baseline characteristics of all subjects, diabetic patients, non-diabetic patients and living kidney donors (mean ± SD)

	all subjects	diabetic patients	non-diabetic patients	living kidney donors	p
Number of subjects	120	40	40	40	///
age (years)	57 ± 14	65 ± 10	50 ± 16	56 ± 12	< 0.0001
gender (male/female)	49 / 71	16 / 24	16 / 24	17 / 23	0.9033
body mass index (kg/m2)	24.3 ± 4.2	25.5 ± 3.5	24.2 ± 4.8	23.2 ± 3.9	0.0449
mean blood pressure (mmHg)	88 ± 11	89 ± 11	87 ± 10	89 ± 12	0.6970
systolic pressure (mmHg)	122 ± 17	126 ± 19	120 ± 17	122 ± 16	0.3513
diastolic pressure (mmHg)	71 ± 10	71 ± 10	71 ± 10	74 ± 12	0.3113
fasting plasma glucose (g/dL)	104 ± 25	124 ± 28	95 ± 16	94 ± 17	<0.0001
hemoglobin A1c (%)	6.3 ± 1.6	8.1 ± 1.5	5.4 ± 0.5	5.4 ± 0.4	<0.0001
total protein (g/dL)	7.0 ± 0.6	7.0 ± 0.6	6.7 ± 0.5	7.2 ± 0.6	0.0055
serum albumin (g/dL)	4.1 ± 0.4	4.0 ± 0.4	3.9 ± 0.3	4.3 ± 0.4	<0.0001
s-creatinine (mg/dL)	0.9 ± 0.5	0.7 ± 0.3	1.2 ± 0.6	0.7 ± 0.1	<0.0001
$eGFR_{cr}$ (mL/min/1.73m2)	66.9 ± 22.0	75.0 ± 20.2	47.9 ± 18.7	78.6 ± 11.6	<0.0001
s-cystatin C (mg/dL)	1.1 ± 0.6 (n = 101)	0.9 ± 0.3 (n = 36)	1.5 ± 0.8 (n = 35)	0.7 ± 0.1 (n = 30)	<0.0001
$eGFR_{cys}$ (mL/min/1.73m2)	76.9 ± 29.0 (n = 101)	80.6 ± 22.4 (n = 36)	53.7 ± 22.8 (n = 35)	101.5 ± 18.8 (n = 30)	<0.0001
C_{in} (mL/min/1.73m2)	71.8 ± 27.0	68.1 ± 20.6	54.6 ± 23.4	93.2 ± 22.9	<0.0001

Measurements of C_{in}

C_{in} was determined by the constant input clearance technique with inulin. According to the method by Horio et al., continuous intravenous infusion of inulin was performed via a forearm antecubital vein in the morning under a fasting state [16]. In brief, the patients received 500 mL of water orally 15 minutes before the infusion. A 1% inulin solution in saline was infused at 300 mL/h for the first 30 minutes, and at 100 mL/min for the following 90 minutes. Patients completely voided their bladders at 45 minutes. Blood samples for the measurement of plasma inulin were collected at the same time. To maintain hydration, 180 mL of water was provided orally at the time of voiding the bladder. Blood and urine samples were taken at the end of the clearance period to measure plasma and urine inulin, respectively. A urine collection period of 90 min was set, in order to increase the accuracy of the clearance study. C_{in} was calculated by the $U_{in}V / P_{in}$ method where U_{in} represents the urinary inulin concentration, V: urinary volume, and P_{in}: plasma inulin concentration. P_{in} was the mean value of the plasma inulin concentration at the beginning and at the end of the clearance period. Plasma inulin concentration was determined colorimetrically using the N-1 naphthylethylenediamine and the anthrone method with a Corning 258 spectrophotometer [17].

Statistical methods

The data are expressed as the mean ± SD. Correlations between two variables were examined using simple regression analysis. All analyses were performed using StatView 5 (SAS Institute Inc., Cary, NC, USA) and SPSS-17 software (SPSS, Chicago, IL, USA) on a Windows computer. The level of statistical significance was set at $p < 0.05$. The agreements between C_{in} and each eGFR were evaluated using the intraclass correlation coefficient (ICC) in diabetic patients, non-diabetic patients and living kidney donors. Z test was performed to compare two correlation coefficients and two ICCs in each group.

Results

Clinical characteristics and renal function

The baseline characteristics of the 120 subjects (40 diabetic patients, 40 non-diabetic patients, 40 living kidney donors) enrolled in the present study are shown in Table 1. The mean $eGFR_{cr}$ and $eGFR_{cys}$ were 66.9 ± 22.0 mL/min/1.73m^2 (diabetic patients 75.0 ± 20.2 mL/min/1.73m^2, non diabetic patients 47.9 ± 18.7 mL/min/1.73m^2, living kidney donors 78.6 ±11.6 mL/min/1.73m^2) and 76.9 ± 29.0 mL/min/1.73m^2 (diabetic patients 80.6 ± 22.4 mL/min/1.73m^2, non diabetic patients 53.7 ± 22.8 mL/min/1.73m^2, living kidney donors 101.5 ± 18.8 mL/min/1.73m^2), respectively. The mean C_{in} was 71.8 ± 27.0 mL/min/1.73m^2 (diabetic patients 68.1 ± 20.6 mL/min/1.73m^2, non diabetic patients 54.6 ± 23.4 mL/min/1.73m^2, living kidney donors 93.2 ± 22.9 mL/min/1.73m^2).

Table 2. Intraclass correlation coefficients (ICC) between C_{in} and each of the eGFR calculations from, diabetic patients, non-diabetic patients and living kidney donors

	C_{in} (mL/min/1.73m²)					
	diabetic patients (n = 40)		non-diabetic patients (n = 40)		living kidney donors (n = 40)	
	ICC	95%CI	ICC	95%CI	ICC	95%CI
eGFRcr	0.699	0.442 - 0.816	0.865	0.759 - 0.926	0.340	0.035 – 0.926
eGFRcys	0.604 (n = 36)	0.202-0.703	0.803 (n = 35)	0.644 - 0.895	0.345 (n = 30)	-0.011 - 0.624

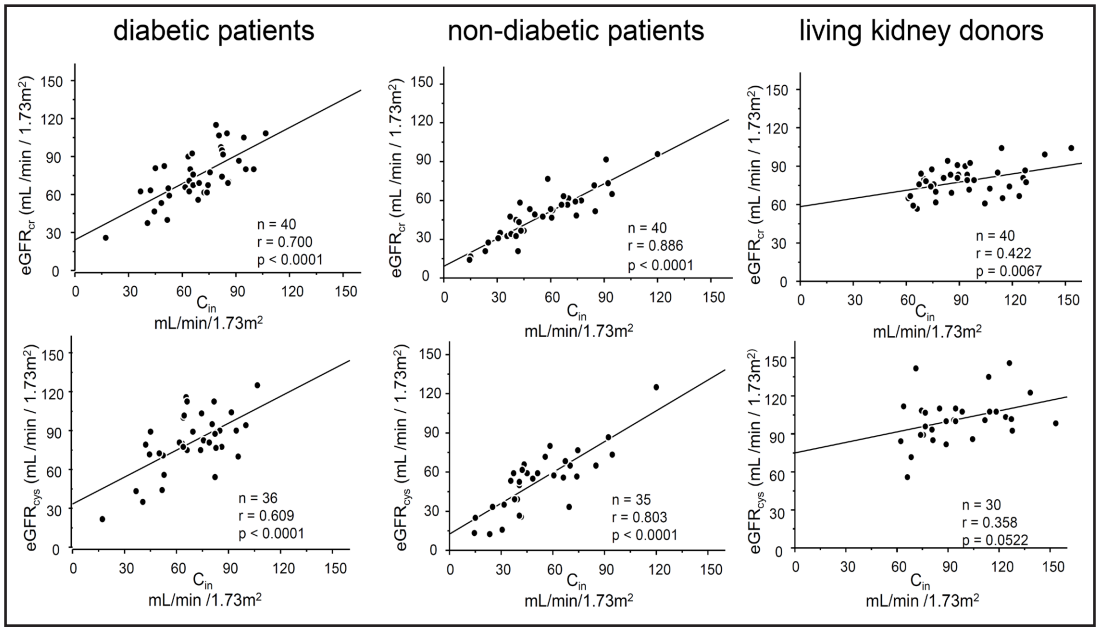

Fig. 1. Relationship between inulin clearance (C_{in}) and glomerular filtration rate estimated based on serum creatinine ($eGFR_{cr}$) and serum cystatin C ($eGFR_{cys}$) in diabetic patients, non-diabetic patients and living kidney donors. There were significant and positive correlations between $eGFR_{cr}$ and C_{in} and between $eGFR_{cys}$ and C_{in} in both diabetic patients and non-diabetic patients. In living kidney donors, there was a significant and positive correlation between C_{in} and $eGFR_{cr}$, and there was a borderline, positive correlation between C_{in} and $eGFR_{cys}$.

Relationship and agreement between C_{in} and each eGFR ($eGFR_{cr}$ and $eGFR_{cys}$) in diabetic patients, non-diabetic patients and living kidney donors

Correlation coefficients and agreements between C_{in} and each of the eGFR calculations ($eGFR_{cr}$ and $eGFR_{cys}$) were examined. As shown in Fig. 1, in diabetic patients, there were significant and positive correlations between C_{in} and each of eGFR. However, as shown in Table 2, there were weak agreements between C_{in} and each of the eGFR in diabetic patients.

As shown in Fig. 1, in non-diabetic patients, there were strong, significant and positive correlations between C_{in} and each of the eGFR. Further, as shown in Table 2, there were strong agreements between C_{in} and each of the eGFR in non-diabetic patients.

As shown in Fig. 1, in living kidney donors, there was a significant and positive correlation between C_{in} and $eGFR_{cr}$. There was a borderline but positive correlation between C_{in} and $eGFR_{cys}$. As shown in Table 2, there were very weak agreements between C_{in} and each of the eGFR in living kidney donors.

We compared the differences between the correlation coefficients and ICCs in the three groups: diabetic patients, non-diabetic patients and living kidney donors. The correlation coefficient between $eGFR_{cr}$ and C_{in} of non-diabetic patients was significantly higher than those of the diabetic patients ($p = 0.0286$) and living kidney donors ($p = 0.0001$)

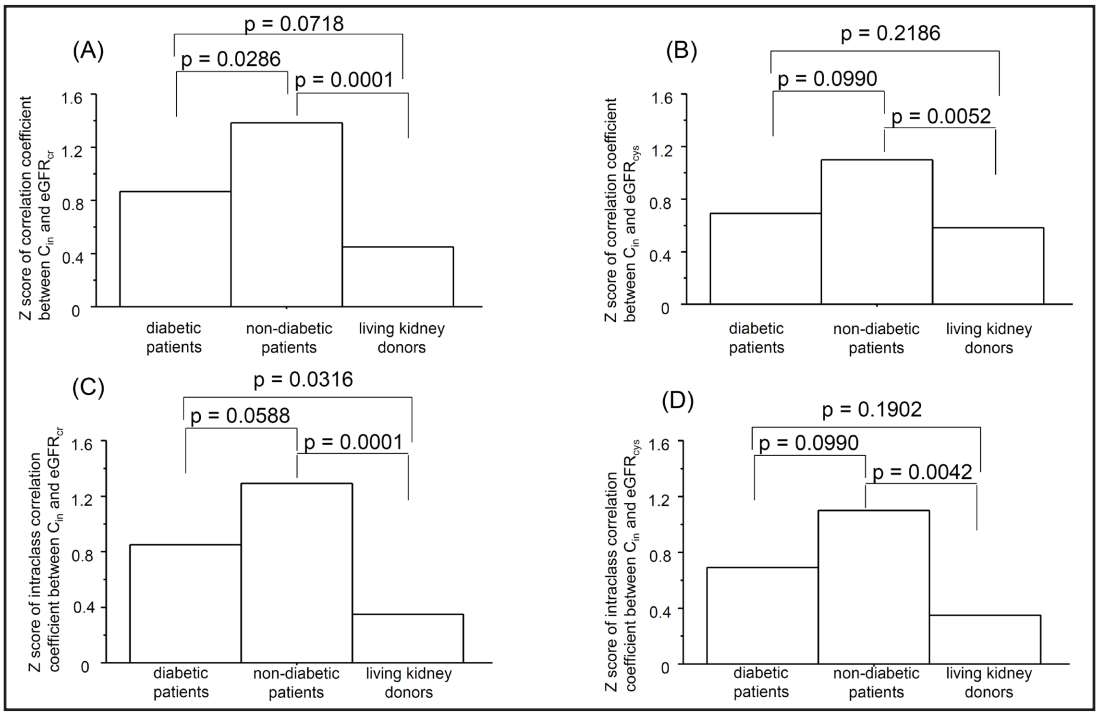

Fig. 2. Z tests were used to compare two correlation coefficients and two intraclass correlation coefficients (ICCs) in each group. (A) The correlation coefficient between $eGFR_{cr}$ and C_{in} of the non-diabetic patients was significantly higher than that of the diabetic patients and living kidney donors, and the correlation coefficient between $eGFR_{cr}$ and C_{in} of the diabetic patients was marginally higher than that of the living kidney donors. (B) The correlation coefficient between $eGFR_{cys}$ and C_{in} of the non-diabetic patients was marginally higher than that of the diabetic patients and significantly higher than that of the living kidney donors, and the correlation coefficient between $eGFR_{cys}$ and C_{in} of the diabetic patients was not significantly different from the living kidney donors. (C) The ICC between $eGFR_{cr}$ and C_{in} of the non-diabetic patients was marginally higher than that of the diabetic patients and significantly higher than that of the living kidney donors, and the ICC between $eGFR_{cr}$ and C_{in} of the diabetic patients was significantly higher than that of the living kidney donors. (D) The ICC between $eGFR_{cys}$ and C_{in} of the non-diabetic patients was marginally higher than that of the diabetic patients and significantly higher than that of the living kidney donors, and the ICC between $eGFR_{cys}$ and C_{in} of the diabetic patients was not significantly different from the living kidney donors.

(Fig. 2 (A)). The correlation coefficient between $eGFR_{cr}$ and C_{in} of the diabetic patients was slightly, but not significantly, higher than that of living kidney donors ($p = 0.0718$) (Fig. 2 (A)). The correlation coefficient between $eGFR_{cys}$ and C_{in} of non-diabetic patients was slightly, but not significantly, higher than that of diabetic patients ($p = 0.0990$) and significantly higher than that of living kidney donors ($p = 0.0052$) (Fig. 2 (B)). The correlation coefficient between $eGFR_{cys}$ and C_{in} of diabetic patients was not significantly different from the living kidney donors ($p = 0.2186$) (Fig. 2 (B)).

The ICC between $eGFR_{cr}$ and C_{in} of non-diabetic patients was slightly, but not significantly, higher than that of diabetic patients ($p = 0.0588$) and significantly higher than that of living kidney donors ($p = 0.0001$) (Fig. 2 (C)). The ICC between $eGFR_{cr}$ and C_{in} of diabetic patients was significant higher than that of living kidney donors ($p = 0.0316$) (Fig. 2 (C)). The ICC between $eGFR_{cys}$ and C_{in} of non-diabetic patients was slightly, but not significantly, higher than that of diabetic patients ($p = 0.0990$) and significantly higher than that of living kidney donors ($p = 0.0042$) (Fig. 2 (D),). The ICC between $eGFR_{cys}$ and C_{in} of diabetic patients was not significantly different from the living kidney donors ($p = 0.1902$) (Fig. 2 (D)).

Discussion

In the present study, we measured inulin clearance (C_{in}), i.e., the gold standard for measuring GFR, and compared the correlation coefficients and agreements between each eGFR and C_{in}, to confirm the validity of eGFR in diabetic patients, non-diabetic patients and living kidney donors. We demonstrated that each eGFR was accurate in non-diabetic patients, that each eGFR was inaccurate in living kidney donors, and that each eGFR was relatively inaccurate in diabetic patients.

In general, C_{cr} overestimates C_{in} [18-21]. This phenomenon has been reported to be caused by creatinine secretion from the renal tubuli [18, 22], in addition to glomerular filtration of creatinine. To overcome the weakness of C_{cr} compared with C_{in}, the MDRD formula of eGFR was developed in 2006, in consideration of serum creatinine, age, gender, and race [23, 24]. The eGFR equation based on serum creatinine, age, and gender was also constructed by the Japanese Society of Nephrology, by directly measuring C_{in} in 763 Japanese subjects [7]. However, since serum creatinine is affected by muscle mass, gender, and age, and since the serum creatinine levels are significantly lower in diabetic patients [8, 19], cystatin C has recently been proposed as a better marker of renal function. Cystatin C is produced by the nucleated cells of the body, and acts as a circulating cysteine proteinase inhibitor [25]. It is known that cystatin C is filtered by the glomeruli and is not affected by muscle mass, gender, and age, as occurs with serum creatinine levels [6]. Serum cystatin C levels and an eGFR equation based on serum cystatin C have been recently proposed as more relevant markers of renal function [4-6]. Horio et al. recently reported eGFR equations using serum cystatin C [26].

In our study, the estimated GFR, as determined by $eGFR_{cr}$ and $eGFR_{cys}$, was accurate in non-diabetic patients. However, we reported in a previous study that both $eGFR_{cr}$ and $eGFR_{cys}$ were higher and inaccurate in diabetic patients compared with non-diabetic patients [9, 10]. We found that there were significant and positive correlations between each of the eGFR / C_{in} ratios and hemoglobin A1c. Accordingly, we proposed a formula for eGFR corrected using HbA1c in our previous study [9, 10]. Further validation studies are needed to construct formulae that are adjusted by glycemic control indices.

In the present study, the estimated GFR of $eGFR_{cr}$ and $eGFR_{cys}$ were inaccurate in living kidney donors. This result also suggests that each eGFR would be inaccurate in healthy subjects with eGFR more than 60 ml/min/1.73m^2. Horio et al. [11] and Kakuta et al. [12] also reported that the Japanese eGFR equation calculated based upon serum creatinine underestimated the GFR in living kidney donors. Consistent with their findings, in the present study, $eGFR_{cr}$ underestimated the GFR in living kidney donors. The estimated GFR based on cystatin C or the combination of serum creatinine and cystatin C was suggested to be better than $eGFR_{cr}$ for the evaluation of GFR in kidney donors [11, 27]. However, in our study, not only $eGFR_{cr}$ but also $eGFR_{cys}$ were inaccurate in living kidney donors. Accordingly, we examined the relationship between the eGFR / C_{in} ratio and clinical parameters, including gender, age, body mass index, glycemic control indices and other general indices. However, there were no significant associations between any of the clinical parameters and each eGFR / C_{in} in the present study (data not shown). This may be partly due to the analysis of a small number of patients (n = 40). In the development of the eGFR equation by the Japanese Society of Nephrology in 2009, few living kidney donors or healthy subjects were included in the total sample population of 763 subjects. Based on the inaccuracy of eGFR (either $eGFR_{cr}$ or $eGFR_{cys}$) in the present study, along with the two previous studies [11, 12], it is suggested that C_{in} should be measured for the evaluation of GFR in living kidney donors or healthy subjects. However, we cannot measure C_{in} for all subjects who are healthy or consult for a medical check-up. We also cannot correct the equation by clinical parameters, because we could not determine any factors that would affect the inaccuracy of eGFR in living kidney donors in the present study.

This study has some limitations. Firstly, the study was performed in a relatively small number of Japanese patients. We could not test the subjects (both those with and without

diabetes) with different GFR throughout whole spectrum (in both groups) and with uniform distribution of values. This was because of the somewhat complicated technique of the inulin clearance measurements and difficulty in obtaining written informed consent from a sufficient number of subjects. However, we evaluated renal function in 40 diabetic patients and 40 non-diabetic patients as well as 40 living kidney donors by inulin clearance (C_{in}) in a single institution. We compared each of the eGFR equations in diabetic patients, non-diabetic patients and living kidney donors, based on serum creatinine and serum cystatin C ($eGFR_{cr}$ and $eGFR_{cys}$). We found that each of the eGFR calculations (not only $eGFR_{cr}$ but also $eGFR_{cys}$) were inaccurate in living kidney donors. Furthermore, we also found that each of the eGFR calculations was accurate in non-diabetic patients. Secondly, in the present study, the effect of antihypertensive agents, such as renin-angiotensin system inhibitors, which could affect GFR [28], was not evaluated in the analysis, since antihypertensive agents were prescribed in only some of the diabetic and non-diabetic patients, but not in the living kidney donors. Thirdly, in this study, we could not find any factors that affected the dissociation between eGFR and C_{in} in living kidney donors. Each of the eGFR calculations ($eGFR_{cr}$ and $eGFR_{cys}$) was inaccurate in living kidney donors. In future, it may be necessary to develop an estimating equation that is corrected based upon some clinical parameters for living kidney donors or healthy subjects.

Conclusion

The two eGFR calculation methods ($eGFR_{cr}$ and $eGFR_{cys}$) were accurate in non-diabetic patients. However, the two eGFR calculations ($eGFR_{cr}$ and $eGFR_{cys}$) were inaccurate in living kidney donors, suggesting that C_{in} should be measured in the evaluation of GFR in living kidney donors. Further studies are needed to construct formulae that are appropriate for living kidney donors or healthy subjects.

Disclosure Statement

All the authors declare that they have no competing interests.

References

1 Moe SM, Drueke TB: The kdigo guideline on dialysate calcium and patient outcomes: Need for hard evidence. Kidney Int 2011;79:478-479.
2 Martirosyan L, Braspenning J, Denig P, Haaijer-Ruskamp FM: Development and validation of prescribing indicators for cardiovascular risk management in type 2 diabetis mellitus patients. Pharmacoepidemiol Drug Saf 2007;16:S101-S102.
3 Horio M, Imai E, Yasuda Y, Watanabe T, Matsuo S, Japanese CD: GFR estimation using standardized serum cystatin c in Japan. Am J Kidney Dis 2013;61:197-203.
4 Kazama JJ, Kutsuwada K, Ataka K, Maruyama H, Gejyo F: Serum cystatin c reliably detects renal dysfunction in patients with various renal diseases. Nephron 2002;91:13-20.
5 Meier P, Froidevaux C, Dayer E, Blanc E: Cystatin C concentration and glomerular filtration rate. Lancet 2001;357:634-635.
6 Laterza OF, Price CP, Scott MG: Cystatin C: An improved estimator of glomerular filtration rate? Clin Chem 2002;48:699-707.
7 Matsuo S, Imai E, Horio M, Yasuda Y, Tomita K, Nitta K, Yamagata K, Tomino Y, Yokoyama H, Hishida A: Revised equations for estimated GFR from serum creatinine in Japan. Am J Kidney Dis 2009;53:982-992.
8 Inaba M, Kurajoh M, Okuno S, Imanishi Y, Yamada S, Mori K, Ishimura E, Yamakawa T, Nishizawa Y: Poor muscle quality rather than reduced lean body mass is responsible for the lower serum creatinine level in hemodialysis patients with diabetes mellitus. Clin Nephrol 2010;74:266-272.

9 Tsuda A, Ishimura E, Ohno Y, Ichii M, Nakatani S, Machida Y, Mori K, Uchida J, Fukumoto S, Emoto M, Nakatani T, Inaba M: Poor glycemic control is a major factor in the overestimation of glomerular filtration rate in diabetic patients. Diabetes Care 2014;37:596-603.
10 Tsuda A, Ishimura E, Inaba M: Response to comment on tsuda et al. Poor glycemic control is a major factor in the overestimation of glomerular filtration rate in diabetic patients. Diabetes care 2014;37:596-603. Diabetes Care 2014;37:e84.
11 Horio M, Yasuda Y, Kaimori J, Ichimaru N, Isaka Y, Takahara S, Nishi S, Uchida K, Takeda A, Hattori R, Kitada H, Tsuruya K, Imai E, Takahashi K, Watanabe T, Matsuo S: Performance of the Japanese GFR equation in potential kidney donors. Clin Exp Nephrol 2012;16:415-420.
12 Kakuta Y, Okumi M, Ichimaru N, Abe T, Nonomura N, Okuyama A, Kojima Y, Isaka Y, Takahara S, Imai E, Horio M: Utility of the Japanese GFR estimation equation for evaluating potential donor kidney function. Clin Exp Nephrol 2010;14:63-67.
13 Report of the expert committee on the diagnosis and classification of diabetes mellitus. Diabetes Care 1997;20:1183-1197.
14 Matsuo S, Imai E, Horio M, Yasuda Y, Tomita K, Nitta K, Yamagata K, Tomino Y, Yokoyama H, Hishida A, Collaborators developing the Japanese equation for estimated GFR: Revised equations for estimated GFR from serum creatinine in Japan. Am J Kidney Dis 2009;53:982-992.
15 Horio M, Imai E, Yasuda Y, Watanabe T, Matsuo S: Performance of GFR equations in Japanese subjects. Clin Exp Nephrol 2013;17:352-358.
16 Horio M, Imai E, Yasuda Y, Hishida A, Matsuo S: Simple sampling strategy for measuring inulin renal clearance. Clin Exp Nephrol 2009;13:50-54.
17 Kimata S, Mizuguchi K, Hattori S, Teshima S, Orita Y: Evaluation of a new automated, enzymatic inulin assay using D-fructose dehydrogenase. Clin Exp Nephrol 2009;13:341-349.
18 Eisner C, Faulhaber-Walter R, Wang Y, Leelahavanichkul A, Yuen PS, Mizel D, Star RA, Briggs JP, Levine M, Schnermann J: Major contribution of tubular secretion to creatinine clearance in mice. Kidney Int 2010;77:519-526.
19 Orita Y, Gejyo F, Sakatsume M, Shiigai T, Maeda Y, Imai E, Fujii T, Endoh M, Jinde K, Haneda M, Sugimoto T, Hishida A, Takahashi S, Hosoya T, Yamamoto H, Hora K, Okada Y, Hosaka S, Oguchi T, Kanno Y, Nishio Y, Yano S, Aikawa K, Yasui K: [estimation of glomerular filtration rate by inulin clearance: Comparison with creatinine clearance]. Nihon Jinzo Gakkai Shi 2005;47:804-812.
20 Brochnermortensen J: Current status on assessment and measurement of glomerular-filtration rate. Clin Physiol 1985;5:1-17.
21 Carrie BJ, Golbetz HV, Michaels AS, Myers BD: Creatinine - an inadequate filtration marker in glomerular-diseases. Am J Med 1980;69:177-182.
22 Miller BF, Winkler AW: The renal excretion of endogenous creatinine in man. Comparison with exogenous creatinine and inulin. J Clin Invest 1938;17:31-40.
23 Levey AS, Bosch JP, Lewis JB, Greene T, Rogers N, Roth D: A more accurate method to estimate glomerular filtration rate from serum creatinine: A new prediction equation. Modification of diet in renal disease study group. Ann Intern Med 1999;130:461-470.
24 Levey AS, Coresh J, Greene T, Stevens LA, Zhang YL, Hendriksen S, Kusek JW, Van Lente F: Using standardized serum creatinine values in the modification of diet in renal disease study equation for estimating glomerular filtration rate. Ann Intern Med 2006;145:247-254.
25 Abrahamson M, Olafsson I, Palsdottir A, Ulvsback M, Lundwall A, Jensson O, Grubb A: Structure and expression of the human cystatin c gene. Biochem J 1990;268:287-294.
26 Horio M, Imai E, Yasuda Y, Watanabe T, Matsuo S: GFR estimation using standardized serum cystatin C in Japan. Am J Kidney Dis 2013;61:197-203.
27 Horio M, Yasuda Y, Kaimori J, Ichimaru N, Kakuta Y, Isaka Y, Matsuo S, Takahara S: Performance of the Japanese glomerular filtration rate equation based on standardized serum cystatin C in potential kidney donors. Transplant Proc 2014;46:314-317.
28 Santoro D, Zappulla Z, Alibrandi A, Andulajevic MT, Licari M, Baldari S, Buemi M, Cernaro V, Campenni A: Cross-sectional evaluation of kidney function in hospitalized patients: Estimated GFR versus renal scintigraphy. Kidney Blood Press Res 2014;39:668-676.