의학박사 학위논문

단일 신장을 가진 환자에서 팬텀 연구를 통한 CT 사구체 여과율 추정

Estimation of glomerular filtration rate (GFR) in patient with single kidney using CT urography: Phantom study and clinical application

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이 논문을 의학박사 학위 논문으로 제출함

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영문요약

Objective: We aimed to examine the correlation between Hounsfield unit (HU) values and contrast agent concentrations via phantom study and applied this result to estimate glomerular filtration rate (GFR) in patients with a single kidney, comparing the result to CKD-EPI (Chronic Kidney Disease Epidemiology Collaboration) eGFR.

Methods: Through computed tomography (CT) HU value of phantom composed of various concentration of contrast media, we derived the regression equation using linear regression analysis. A total of 43 patients (mean age ± standard deviation [SD], 65.9 ± 8.7 years; 13 men) with single kidney who underwent CT urography from October 2020 to December 2020 was included. In each phase of the scan, we semiautomatically outlined the kidney contour on each slice and calculated the number of voxels and the sum of HU values for the kidney. Using the regression slope obtained from phantom study, we estimated the amount of contrast agent added to the kidney parenchyma. Correlation analyses between these ratios of estimated contrast amount to injected contrast agent and CKD-EPI eGFR values were performed by using Pearson correlation coefficient. Correlation between the ratios of calculated contrast amount in the kidney to the mean HU value of the renal artery and CKD-EPI eGFR values was also evaluated using Pearson correlation coefficient.

Results: Phantom study showed that mean CT HU value showed linear relationship with iodine concentration and the estimated slope of the regression line was 27.9. Calculated amount of contrast agent in the renal parenchyma was gradually increasing from corticomedullary to excretory phase (corticomedullary phase, 537.2 ± 150.2 mg; nephrographic phase, 698.4 ± 174.0 mg; excretory phase, 797.4 ± 216.7 mg [all values were expressed as the means ± SD]). At the corticomedullary and nephrographic phase, correlation analysis between the ratio of estimated contrast amount to injected contrast agent and CKD-EPI eGFR demonstrated a weakly positive correlation with Pearson correlation coefficient of 0.295 (95% confidence interval [CI]: –0.005 – 0.547, p value = 0.055) and 0.337 (95% CI: 0.041 – 0.579, p value = 0.027), respectively, although showing an overall upward trend. At the excretory phase, it demonstrated a moderately positive correlation with

Pearson correlation coefficient of 0.549 (95% CI: 0.297 – 0.729, p value < 0.001). Correlation analysis between the ratio of calculated contrast amount in the kidney to the mean HU value of the renal artery and CKD-EPI eGFR showed a weakly positive correlation on nephrographic phase with Pearson correlation coefficient of 0.484 (95% CI: 0.215 – 0.685, p value = 0.001). At the corticomedullary and excretory phase, it demonstrated a moderately positive correlation with Pearson correlation coefficient of 0.609 (95% CI: 0.378 – 0.769, p value < 0.001) and 0.665 (95% CI: 0.455 – 0.804, p value < 0.001), respectively.

Conclusion: There was weakly to moderately positive correlation between the calculated amount of contrast media using CT attenuation and CKD-EPI eGFR. The ratio of calculated contrast amount to the HU value of renal artery showed weak to moderate correlation with CKD-EPI eGFR, showing higher correlation coefficient. Among the CT phases, excretory phase showed the highest correlation.

차 례

표 목차 및 그림 목차

Introduction

For patients who are planning to undergo unilateral radical nephrectomy due to kidney donation or unilateral renal tumor, it is important to predict how much the glomerular filtration rate (GFR) will decrease after surgery. Formulas from MDRD (Modification of Diet in Renal Disease) and CKD-EPI (Chronic Kidney Disease Epidemiology Collaboration) are used to estimate GFR using creatinine levels in the blood, age, and other factors (1-3). These methods can represent the single-kidney GFR for patients with single kidney, but for patients with both kidneys, it is not possible to obtain the single-kidney GFR for each kidney separately, as the estimated GFR value is the combined value for both kidneys. Additionally, these methods rely on creatinine levels, which may be less accurate in cases of extreme age, severe underweight or overweight. Renal dynamic imaging using radioactive isotope 99mTc-DTPA (technetium-99m-diethylenetriaminepetaacetic acid) are primarily used to obtain the single-kidney GFR by using the Gates method (4-8). This method has the advantage of estimating GFR for each kidney, but it is time-consuming and exposes the patient to radiation.

Iodinated contrast agents commonly used in computed tomography (CT) scans are excreted through glomerular filtration in the kidneys with no secretion or resorption, similar to inulin (9). Thus, iodinated contrast agents can be used as tracer for measuring GFR. The multidetector CT scanner is a reliable tool for investigating glomerular filtration of the iodinated contrast agents due to a good linear relationship between CT attenuation value and concentration of contrast media (6, 10, 11). Since contrast-enhanced CT is almost always performed to evaluate focal renal lesions, renal parenchyma, or renal vasculature before nephrectomy, if GFR can be estimated for each kidney using the CT attenuation difference before and after contrast injection, there may be advantages in reducing radiation exposure and cost by avoiding additional exams such as 99mTc-DTPA scan. In addition, it has advantage in predicting postoperative GFR after surgery using kidney volume and attenuation measured on CT scan.

There are some studies estimating GFR using kidney volume and CT Hounsfield unit (HU) values before and after contrast enhancement (6-8, 12-15). Although there was slight

overestimation or underestimation compared to 99mTc-DTPA scans, relatively accurate GFR estimation was possible (6, 7). However, these studies used various methods to CT-GFR measurement, including those that only measured the kidney, those that included the renal sinus and collecting system, and those that measured the urinary system separately, leading to controversial results.

In this study, we first performed a phantom study to measure the HU values based on the concentration of contrast agents under the similar scanning parameters as CT urography. Then we examined the correlation between HU values and contrast agent concentrations, and applied this result to estimate GFR in patients with a single kidney, comparing the result to CKD-EPI eGFR.

Materials and Methods

CT phantom

The phantom consisted of twelve cylindrical tubes with various concentration of iodinated contrast media. Contrast agent (Ioversol, Optiray 320; Mallinckrodt Medical, St Louis, Mo) was used to mix with normal saline for each cylinder, resulting in iodine concentrations of 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, 2, 3, 4, 5, and 6 mg/mL. The phantom was scanned using CT scanner at 120 kVp (similar to CT urography) and 200 mA.

The mean CT HU values were measured for each concentration by a radiologist (M.Y.P). After confirming the linear relationship between CT HU values and the concentration of contrast media by creating a scatterplot, we derived the regression equation and calculated the slope of the regression line using linear regression analysis.

Study Population

Our institutional review board approved this study (approval number: 2023-0091) and waived the need for informed consent because it was retrospective in nature.

We searched our institutional electronic database for patients with single kidney who underwent CT urography from October 2020 to December 2020. The exclusion criteria are as follows: (a) patients with lesions such as large cysts or hydronephrosis in the single kidney, (b) inappropriate CT images due to severe artifacts or inaccurate scan timing after contrast injection, and (c) patients who did not undergo CKD-EPI eGFR testing within a week of CT exam date. Ultimately, 43 patients were included. The clinical data of each patient were obtained from the electronic medical records, including age, sex, dates of CT urography, CKD-EPI eGFR level, cause of single kidney, and the duration from when the patient became a person with a single kidney to the date of CT scan.

Image Acquisition

Patients underwent multiphase CT examinations on a 16- or 64- row multidetector CT scanner (LightSpeed 16 or Optima CT660, GE Healthcare; Somatom Sensation 16, Siemens Healthcare). Unenhanced, corticomedullary phase, nephrographic phase, and excretory phase images were obtained. 100-140 mL of contrast agent (Ioversol, Optiray 320; Mallinckrodt Medical, St Louis, Mo) was administered at a rate of 2–3 mL/s using a power injector.

The corticomedullary phase was acquired by using automated bolus triggering. The nephrographic phase was acquired at a fixed scan delay of 75 seconds after the initiation of the contrast injection. The excretory phase was obtained at a fixed scan delay of 240 seconds after the initiation of the contrast injection. The scanning parameters were as follows: pitch, 1.5; tube voltage, 120 kVp; automatic tube current modulation with tube current set to 140–240 mA; and slice thickness, 2-5 mm.

Image Analysis

Digital Imaging and Communications in Medicine data of the CT images were loaded to the ImageJ (Bethesda, Maryland; http://rsbweb.nih.gov/ij/). In each phase of the scan, we semiautomatically outlined the kidney contour on each slice, excluding the renal pelvis and renal hilar vessels. For each phase, we calculated the total number of voxels and the sum of HU values for the kidney. The mean HU value of renal artery was also measured in each phase. These values could be derived automatically using ImageJ software. The increase in HU values was calculated as the difference between the sum of HU value of all voxels on post-contrast image and on pre-contrast image in each phase.

Using the CT scanning parameters of pixel size and slice thickness, the voxel size was calculated. Kidney volume was determined by multiplying the voxel count obtained from ImageJ software by the voxel size.

Measurement of CT contrast amount in the single kidney

The increase in HU values of each phase was divided by the value of regression slope obtained from the regression analysis of phantom study, which allowed to determine the added concentration of contrast agent. By multiplying the added contrast concentration by the voxel volume, we estimated the amount of contrast agent added to the kidney parenchyma. Then, the ratio of estimated amount of added contrast agent to the actual amount of injected contrast agent was calculated.

Statistical Analysis

Continuous variables were expressed as the means ± standard deviations (SD), and categorical variables as numbers and percentages.

Correlation analysis between these ratios of estimated contrast amount to injected contrast agent and CKD-EPI eGFR values were performed by using Pearson correlation coefficient. We also conducted correlation analysis between the measured amount of contrast agent divided by the mean HU value of renal artery and CKD-EPI eGFR. Pearson correlation coefficients (*r*) were interpreted as follows: 0–0.20, no association; 0.21–0.50, weakly positive correlation; 0.51–0.80, moderately positive correlation; 0.81–1.00, perfect correlation (16).

Statistical analyses were performed using SPSS version 21.0 (IBM Corp., Armonk, NY, USA) and Medcalc version 14.8.1 (Medcalc Software, Ostend, Belgium). A p value of less than 0.05 was considered statistically significant.

Results

Phantom Study

CT image of phantom composed of twelve tubes with various iodine concentration was shown in Figure 1. We created a scatterplot of mean CT HU value versus the iodine concentration (Figure 2), which showed linear relationship between two variables. The derived regression equation was as follows:

$$Y = 27.9 \times X + 10.4$$

where the variable X represented the iodine concentration and the variable Y represented the mean CT HU value. The estimated slope of the regression line was 27.9 HU·mL/mg.

Patient Characteristics

A total of 43 patients (mean age ± SD, 65.9 ± 8.7 years; 13 men) with single kidney were included in this study. Most patients (37 patients, 86.0 %) underwent unilateral nephrectomy due to urothelial carcinoma. One patient had congenital unilateral renal agenesis. The mean interval between the date of nephrectomy (excluding one patient with congenital unilateral renal agenesis) and the CT date was 47.4 months.

Mean CKD-EPI eGFR was 62.2 and the kidney volume measured on CT images ranged from 100.9 to 300.8 cm^3. The patient characteristics are summarized in Table 1.

Measurement of the Amount of Contrast Agent

According to the results of the phantom study, it was found that the change in CT HU value was proportional to a difference of 27.9 times the iodine concentration.

$$\Delta \text{ HU} = \text{HU}_{post} - \text{HU}_{pre} = 27.9 \text{ x } (\text{C}_{post} - \text{C}_{pre})$$

$$\Delta \text{ C} = \text{C}_{post} - \text{C}_{pre} = \Delta \text{ HU} / 27.9$$

Figure 1. CT image of phantom composed of twelve tubes with various iodine concentration.

(A-L) 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, 2, 3, 4, 5, and 6 mg/mL

Abbreviations: CT, computed tomography

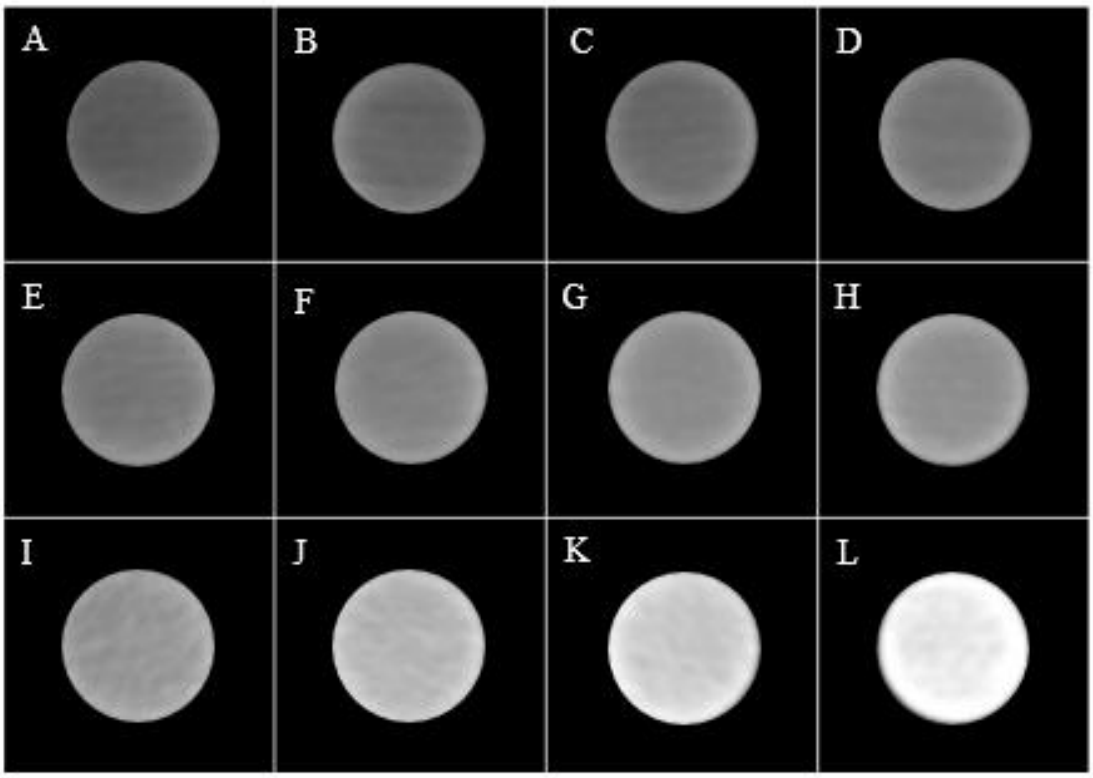


Figure 2. Scatterplot of mean CT HU value versus the iodine concentration with regression line

Abbreviations: CT, computed tomography; HU, Hounsfield unit

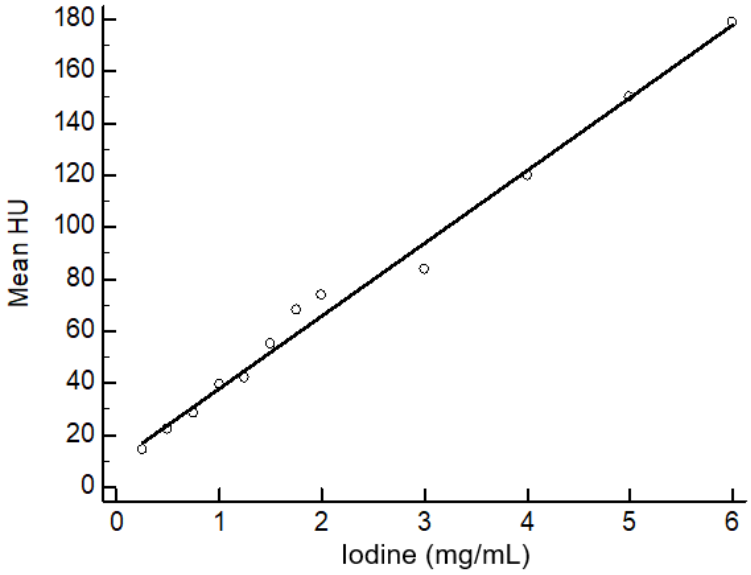


Table 1. Patient characteristics

Characteristic	Value
Age (years)*	65.9 ± 8.7
Sex	
Male	13 (30.2 %)
Female	30 (69.8 %)
Interval from nephrectomy date to CT date (months)*,**	47.4 ± 71.9
CKD-EPI eGFR*	62.2 ± 13.1
Cause of single kidney	
Urothelial carcinoma	37 (86.0 %)
Renal cell carcinoma	3 (7.0 %)
Chronic pyelonephritis	1 (2.3 %)
Donor nephrectomy	1 (2.3 %)
Congenital unilateral renal agenesis	1 (2.3 %)

* Continuous values are presented as the mean ± standard deviation.

** Excluding one patient with congenital unilateral renal agenesis

All other data are numbers of patients, with percentages in parentheses.

Abbreviations: eGFR, estimated glomerular filtration rate

HU*pre* and HU*post* means the HU value of kidney parenchyma on unenhanced and contrast enhanced images, retrospectively. Similarly, C*pre* and C*post* means iodine concentration of kidney parenchyma on unenhanced and contrast enhanced images. As shown in the aforementioned equation, CT HU value increase of the entire kidney was calculated for each corticomedullary, nephrographic, and excretory phase, and then divided by 27.9. The resulting value was then multiplied by the voxel volume to calculate the amount of contrast agent present in the renal parenchyma at that time. Calculated amount of contrast agent in the renal parenchyma was gradually increasing from corticomedullary to excretory phase (corticomedullary phase, 537.2 ± 150.2 mg; nephrographic phase, 698.4 ± 174.0 mg; excretory phase, 797.4 ± 216.7 mg).

Correlation between the contrast amount and CKD-EPI eGFR

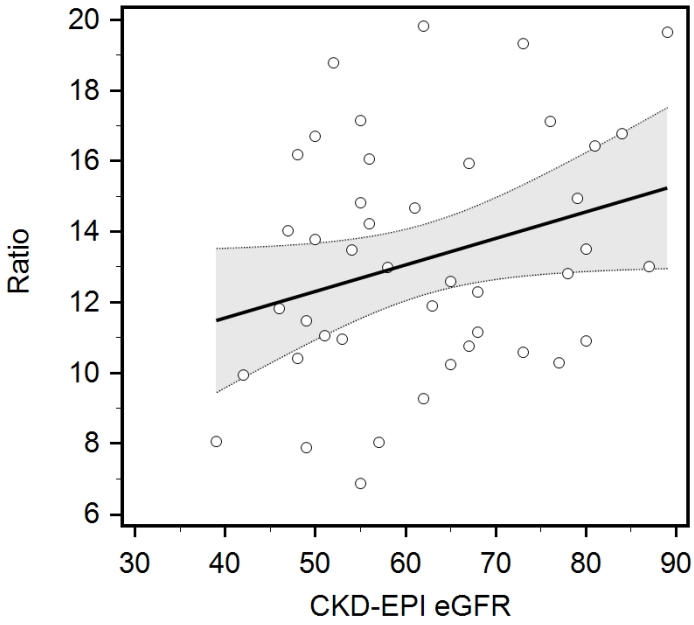
We calculated the ratio of the estimated amount of contrast agent to the amount of contrast agent actually injected. We conducted correlation analysis between the ratio at each phase and CKD-EPI eGFR obtained through blood tests. At the corticomedullary and nephrographic phase, it demonstrated a weakly positive correlation with Pearson correlation coefficient (r) of 0.295 and 0.337 (p value = 0.055 and 0.027, respectively), although showing an overall upward trend. At the excretory phase, it demonstrated a moderately positive correlation with Pearson correlation coefficient (r) of 0.549 (p value < 0.001). Correlations between the ratios of the amount of calculated and injected contrast agent and CKD-EPI eGFRs are shown in Figure 3 and Table 2.

We also divided the measured amount of contrast material in the kidney by the mean HU value of renal artery. Correlation analysis between the resulting values and CKD-EPI eGFR showed a moderately positive correlation at the corticomedullary and excretory phase with Pearson correlation coefficient (r) of 0.609 and 0.665 (p value < 0.001), respectively. At the nephrographic phase, the resulting values and CKD-EPI eGFR showed a weakly positive correlation with Pearson correlation coefficient (r) of 0.484 (p value = 0.001) (Table 3, Figure

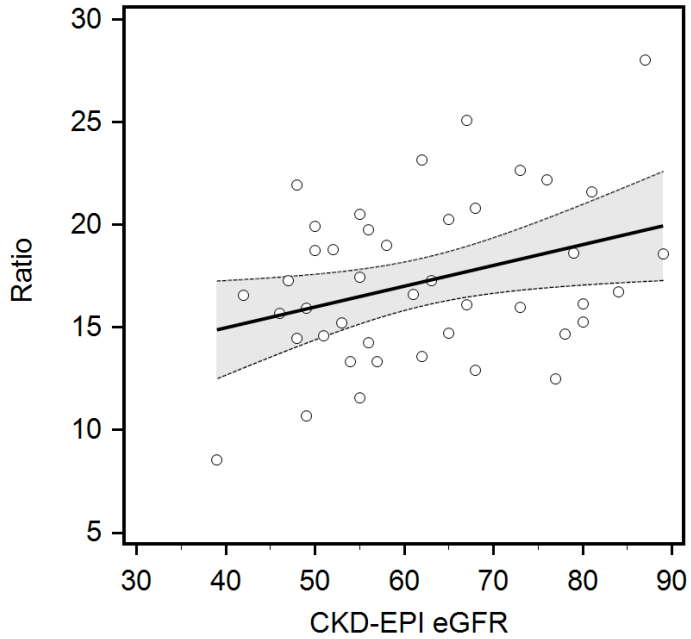
4).

Figure 3. Correlations between the ratios of the amount of calculated and injected contrast agent and CKD-EPI eGFRs

(A) Corticomedullary phase



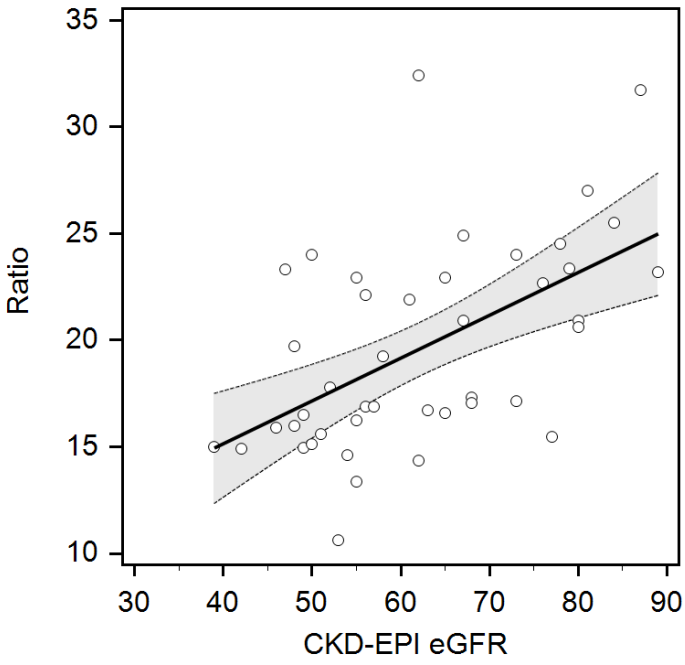
(B) Nephrographic phase



Abbreviations: eGFR, estimated glomerular filtration rate

Figure 3. Continued

(C) Excretory phase



Abbreviations: eGFR, estimated glomerular filtration rate

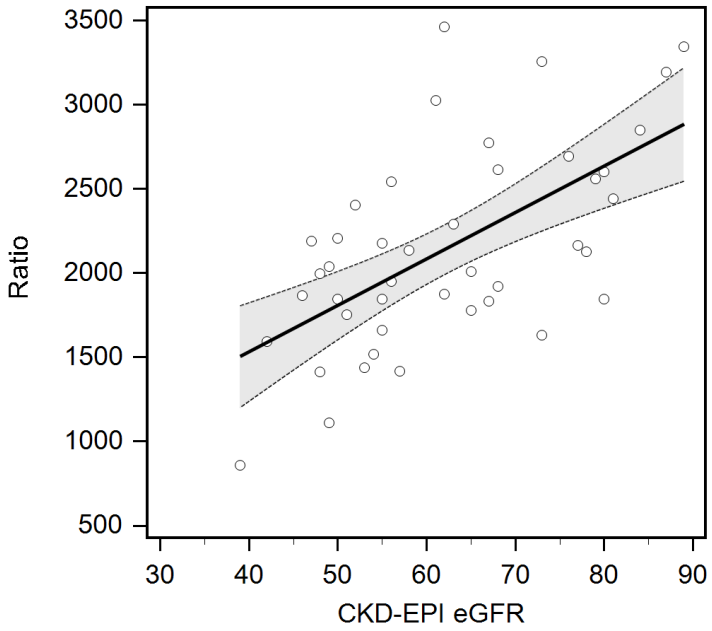
Table 2. Correlations between the ratios of the amount of calculated and injected contrast agent and CKD-EPI eGFRs

	Pearson correlation analysis	
	r (95% CI)	P value
Corticomedullary phase	0.295 (–0.005 – 0.547)	0.054
Nephrographic phase	0.337 (0.041 – 0.579)	0.027
Excretory phase	0.549 (0.297 – 0.729)	<0.001

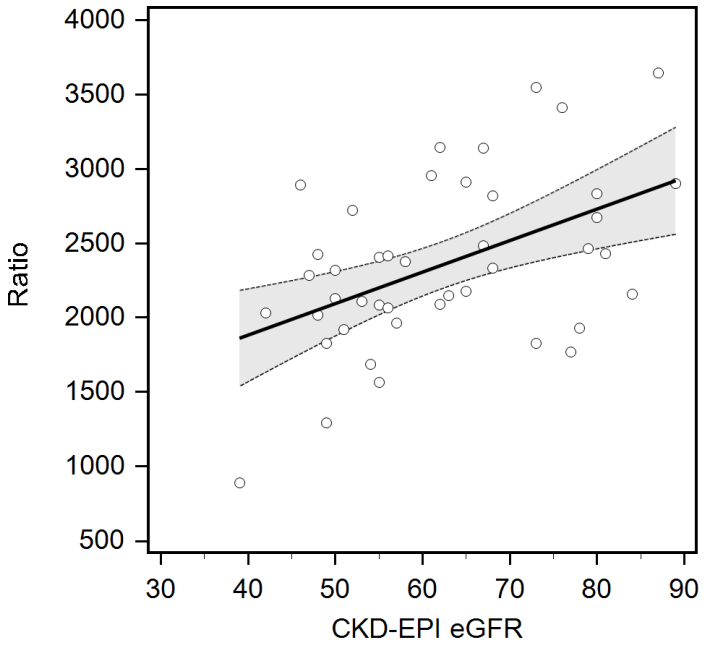
Abbreviations: eGFR, estimated glomerular filtration rate; CI, confidence interval

Figure 4. Correlations between the ratios of the calculated contrast amount to the mean HU value of renal artery and CKD-EPI eGFRs

(A) Corticomedullary phase



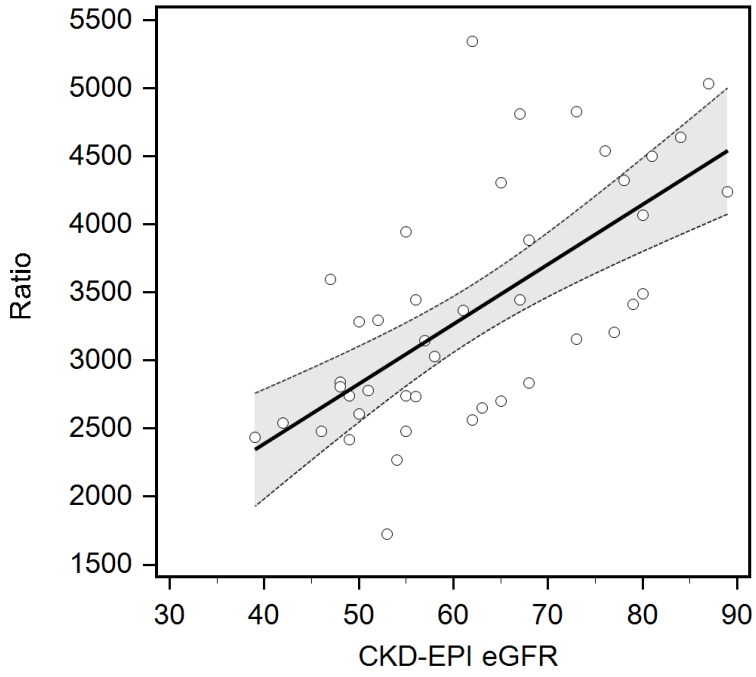
(B) Nephrographic phase



Abbreviations: eGFR, estimated glomerular filtration rate

Figure 4. Continued

(C) Excretory phase



Abbreviations: eGFR, estimated glomerular filtration rate

Table 3. Correlations between the ratios of the calculated contrast amount to the mean HU value of renal artery and CKD-EPI eGFRs

	Pearson correlation analysis	
	r (95% CI)	P value
Corticomedullary phase	0.609 (0.378 – 0.769)	<0.001
Nephrographic phase	0.484 (0.215 – 0.685)	0.001
Excretory phase	0.665 (0.455 – 0.804)	<0.001

Abbreviations: HU, Hounsfield unit; eGFR, estimated glomerular filtration rate; CI, confidence interval

Discussion

In this study, we tried to measure the amount of iodinated contrast material in the renal parenchyma and compare with the CKD-EPI eGFR. We found that weakly to moderately positive correlation between the amount of contrast material calculated using CT attenuation and CKD-EPI eGFR. Among the CT phases, excretory phase showed the highest correlation. The other phases showed only weak association. It can be speculated that as the contrast material circulates throughout the body and is taken up by other organs before returning to the kidneys, it takes time for the contrast to gradually enter the renal cortex to medulla, leading to an increasing association over time. As the enhancement of renal parenchyma can be caused by renal perfusion as well as filtration and some of the contrast may already be excreted through the urinary tract on excretory phase, the correlation did not appear to be strong enough than expected.

The renal clearance of the contrast agent is calculated by dividing the amount of the contrast material filtration by its plasma concentration. Considering this point, we divided the calculated amount of contrast agent in the kidney by the mean HU value of the renal artery, and performed additional correlation analysis between the resulting values and CKD-EPI eGFR. It also showed weakly to moderately positive correlation with slightly higher Pearson correlation coefficients than the previous analyses and the strongest correlation on excretory phase among the CT phases.

There have been several attempts to estimate single-kidney GFR using CT images (6-8, 12-15). In a study by Herts et al, a formula was derived to measure GFR using kidney volume obtained on CT image in kidney donors (12). This study only used renal parenchymal volume and did not measure CT attenuation of the kidney. Another study by Zheng et al developed a split GFR prediction model using renal volume only (8).

Two other studies by Yuan et al and You et al measured CT-GFR using CT attenuation difference (6, 7). These studies obtained area under the aortic time-attenuation curve and estimated CT GFR using volume and HU value of kidney and urinary tract. After that, CT

GFR was compared with renal dynamic imaging GFR obtained by using the Gates method. Both studies showed yielded good correlation with Gates-GFR, although one revealed slight overestimation and the other showed slight underestimation. From the results, it was validated that GFR can be estimated using CT attenuation.

There is also a study estimating split renal function and comparing the correlation at each phase (14). They calculated the proportional factor using the volume and HU value of both kidneys and applied it to serum creatinine-based eGFR to estimate split renal function. Among the CT phases, nephrographic phase showed the best correlation between CT split eGFR and Gates GFR. The scan timing of nephrographic phase on that study was similar to that of excretory phase on our study, which suggested that the consistent results were derived in both studies.

This study tried to measure the actual amount of contrast media using preliminary phantom study. However, there may be a difference between the actual amount of contrast excreted through glomerular filtration and the calculated value. It is thought that the differences between the in vivo and in vitro environments resulted in disparate outcomes. As contrast agents were taken up by other organs and there was continuous perfusion in the kidneys, the increase in CT attenuation of the kidneys did not solely reflect filtration. Additionally, various hemodynamic factors associated with unilateral nephrectomy might have contributed to the observed results. According to a 5-year prospective study about the cardiovascular effects of kidney donors, left ventricular mass and pulse wave velocity increased at 12 months after donation. At 5 years after donation, both showed no significant difference between kidney donors and healthy controls (17).

The renal dynamic imaging with radioactive isotope 99mTc-DTPA using Gates method is the widely adopted clinical method to assess split renal function (4-8). However, it has a lengthy examination time (more than half an hour) and applies a radiation dose to the patient. Furthermore, there are several factors that can impact the accuracy of renal dynamic imaging, such as the depth and position of the kidney, the selection of the background region of interest, the presence of hypervascular tumor of the kidney, and motion artifacts (4-6). CT

examinations using iodine contrast media are usually performed to evaluate the morphology of renal parenchyma, vasculature, and urinary tract before unilateral nephrectomy. Considering the characteristics of CT iodine contrast media excreted through glomerular filtration, CT attenuation increase after contrast injection may show correlation with GFR. This correlation was also proved in multiple previous studies, and this study also showed moderate correlation between GFR and CT attenuation increase. Estimating GFR using CT attenuation offers the advantage of being non-invasive and free from the need for additional radiation exposure and costs in assessing renal function. If more accurate methods developed through further researches, it may be possible to predict postoperative GFR using kidney volume and attenuation increase of preoperative CT scan. It may be also possible to preselect individuals at risk for postoperative renal failure. Moreover, with follow-up CT imaging, we can predict individuals who are at risk of contrast media-induced nephrotoxicity.

There are some limitations of this study. First, this study is single-institution retrospective study with a relatively small sample size. Therefore, expanding this study to include multi-center studies and a larger patient population would further enhance the validity of the results. Second, we compared the measured value with CKD-EPI eGFR. CKD-EPI eGFR is dependent on creatinine level and less accurate in patients with extreme age, severe underweight or overweight. Because the date of the CT scan and serum creatinine level test were not always the same, fluctuations in serum creatinine values may undermine the significance of our findings.

In conclusion, there was weakly to moderately positive correlation between the calculated amount of contrast media using CT attenuation and CKD-EPI eGFR. The ratio of calculated contrast amount to the HU value of renal artery also showed weak to moderate correlation with CKD-EPI eGFR, showing higher correlation coefficient. Among the CT phases, excretory phase showed the highest correlation. Further studies are needed to increase the accuracy, which would be helpful for evaluating the renal function as well as the urinary tract and kidney without additional radiation dose and cost.

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단일 신장을 가진 환자에서 팬텀 연구를 통한 CT 사구체 여과율 추정

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본 연구는 팬텀 연구를 통해 CT 의 Hounsfield unit (HU) 값과 조영제 농도 간의 상관관계를 알아보고, 이 결과를 단일 신장을 가진 환자의 GFR 추정에 적용하여 혈액검사를 통해 얻은 CKD-EPI (Chronic Kidney Disease Epidemiology Collaboration) eGFR 값과 비교하고자 하였다.

다양한 농도의 조영제로 구성된 팬텀 모형으로 각각의 조영제 농도에 따른 전산화 단층촬영(computed tomography, CT)의 HU 값을 구하고, 이를 선형회귀분석을 이용하여 회귀식을 도출하였다. 2020 년 10 월부터 2020 년 12 월까지 CT 요로조영술을 시행한 43 명의 단일 신장 환자 (평균 연령 ± 표준편차, 65.9 ± 8.7 세)가 포함되었다. 각각의 CT 이미지에서 신장 윤곽을 그려 신장을 구성하는 voxel 수와 신장의 HU 값의 총 합을 구하였다. 앞서 얻은 팬텀 연구의 회귀식 기울기를 이용하여 신장 실질에 추가된 조영제의 양을 추정하였고, 이 추정치와 실제 주입된 조영제의 비율을 구하였다. Pearson 상관계수를 이용한 상관분석을 통해 이 비율과 CKD-EPI eGFR 과의 상관관계를 분석하였다. 또한 신장 실질의 조영제 양과 신장 동맥 HU 의 비율을 구하여 이 값과 CKD-EPI eGFR 과의 상관관계 또한 분석하였다.

팬텀 연구에서 평균 CT HU 값은 조영제 농도와 선형 관계를 보였고 회귀선의 추정 기울기는 27.9 로 계산되었다. 이를 통해 신장 실질에서의 조영제 양을 측정하였을 때, 피질기(corticomedullary phase)에서 배설기(excretory phase)로 갈수록 점차 조영제 양이 증가하는 것으로 나타났다 (corticomedullary phase, 537.2 ± 150.2 mg; nephrographic phase, 698.4 ± 174.0 mg; excretory phase, 797.4 ± 216.7 mg [모든 값은 평균 ± 표준편차로 표시함]). 신장 내 조영제 추정량과 실제 주입량의 비율은 CKD-EPI eGFR 값과 약하거나 중간 정도의 상관관계를 보였다. 그 중 배설기에 0.549 로 가장 높은 Pearson 상관계수를 보였다 (95% CI: 0.297 – 0.729, p value

<0.001). 신장 내 조영제 추정량을 신장 동맥 HU 값으로 나누어 이 값을 CKD-EPI eGFR 과 비교해 보았을 때 역시 약하거나 중간 정도의 상관관계를 보였으며, 앞선 상관분석보다 전반적으로 다소 높은 상관 계수를 보였다. 또한 마찬가지로 배설기에 0.665 로 가장 높은 Pearson 상관계수를 보였다 (95% CI: 0.455 – 0.804, p value <0.001).

결론적으로, CT HU 값으로 신장 실질 내에 관찰되는 조영제 양을 계산해 보았을 때, 그리고 신장 실질 내 조영제 양과 신장 동맥의 HU 값의 비율을 구했을 때 모두 CKD-EPI eGFR 값과 약하거나 중등도의 상관관계를 보였다. 또한 여러 CT 시기 중에서는 배설기가 가장 높은 상관관계를 보였다.