Original article

Comparison of glomerular filtration rate measured between anterior and posterior image processing using Gates' method in an ectopic pelvic kidney

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Objective The aim of this study was to evaluate the difference in measured glomerular filtration rate (GFR) of an ectopic pelvic kidney between anterior and posterior image processing using Gates' method of renal dynamic imaging.

Methods A total of 10 patients were studied retrospectively, with a single ectopic kidney in the pelvic cavity and a contralateral kidney at its normal anatomical position confirmed by ultrasound, computed tomography, renal dynamic imaging, etc. All images of ectopic kidneys were processed, and GFRs were measured using anterior and posterior Gates' method of renal dynamic imaging, respectively. The contralateral normal kidney was only processed on posterior imaging. The total GFR_{ant} of one patient, which was equal to the sum of the GFR of a normal kidney on posterior imaging and the GFR of an ectopic kidney on anterior imaging, was compared with the total GFR_{post} of two kidneys on posterior imaging, with the GFR_{two-sample} from the two-sample method, and with the estimated GFR in the Chronic Kidney Disease Epidemiology Collaboration equation. All correlation analyses were carried out between GFRs obtained from three methods, and all patients were followed up. For statistical analysis, nonparametric rank tests were used, Bland-Altman graphs were plotted.

Results The mean GFR of the ectopic kidney on anterior imaging was 27.48 ± 12.24 ml/min/1.73 m². It was higher than the GFR (10.71 ± 4.74 ml/min/1.73 m²) on posterior imaging ($t = -2.803$, $P < 0.05$). There were statistical

differences between the total GFR_{ant} and the total GFR_{two-sample} ($Z = -2.295$, $P < 0.05$), between the total GFR_{ant} and the total GFR_{post} ($Z = 2.599$, $P < 0.01$), between the total GFR_{two-sample} and the total GFR_{post} ($Z = -2.191$, $P < 0.05$), and between the total GFR_{ant} and the estimated glomerular filtration rate ($Z = -2.803$, $P < 0.01$). The bias of the total GFR_{ant} was different from that of the total GFR_{post} ($Z = -2.191$, $P < 0.05$). There were no differences in the precision and accuracy within 30% of the total GFR_{ant} and that of the total GFR_{post} (precision: $F = 0.351$, $P > 0.05$), but there were statistical differences in the accuracy within 10% of the total GFR_{ant} and that of the total GFR_{post} ($P < 0.05$).

Conclusion The GFR measured using Gates' method of anterior image processing was more accurate than the GFR obtained on posterior image processing in reflecting the function of an ectopic pelvic kidney in renal dynamic imaging. *Nucl Med Commun* 37:519–524 Copyright © 2016 Wolters Kluwer Health, Inc. All rights reserved.

Nuclear Medicine Communications 2016, 37:519–524

Keywords: ectopic kidney, glomerular filtration rate, renal dynamic imaging

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Received 22 October 2015 Revised 7 December 2015

Accepted 7 December 2015

Introduction

Ectopic kidney is a relatively rare congenital anomaly in the position of one or both kidneys. It results from the kidney failing to ascend to its normal anatomical position properly in the upper abdomen from its origin in the true pelvis. The function of an ectopic kidney varies on the basis of its shape, size, position, and rotation. Ultrasonography and computed tomography (CT) can show the location, size, and shape of an ectopic kidney. Computed tomography angiography can show the artery of an ectopic kidney and a CT urogram can show the collection system of an ectopic kidney. They are useful

in the management of an ectopic kidney. However, they are less useful in estimating the function of an ectopic kidney than renal dynamic imaging. However, because of more clear renal images in the posterior view, all kidney images on renal dynamic imaging were usually processed by posterior imaging and their glomerular filtration rates (GFRs) were measured using Gates' method in the posterior view, not in the anterior view. The locations of the ectopic kidney and the transplant kidney in the pelvis are closer to the skin of the lower abdomen than to the skin of the lumbar region. The ectopic and transplant kidneys can be seen clearly in the anterior view. In this way, GFRs measured using Gates' method in the anterior view can be more exact than those measured in the posterior view. To our knowledge, there has been no study reporting a comparison of the measured GFRs of

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an ectopic pelvic kidney between anterior and posterior view processing using Gates' method of renal dynamic imaging.

Materials and methods

Patients

Consecutive patients with an ectopic pelvic kidney ($n=10$) referred for renal dynamic imaging during 2010–2013 were enrolled retrospectively in this study (three men, seven women, mean age 26.3 ± 18.3 years, age range 5–68 years). These 10 patients with an ectopic pelvic kidney were diagnosed by ultrasonography, CT, MRI, and so forth. Of these 10 patients, six were diagnosed by chance during a physical examination. The remaining patients had presented to the hospital for other medical complaints. All images of the ectopic kidneys in the 10 patients were processed by anterior and posterior imaging, and their GFRs were measured using Gates' method of renal dynamic imaging in the anterior and posterior views, respectively. The GFRs of kidneys in the normal location were only measured using Gates' method of posterior imaging. The total GFR (GFR_{ant}) of one patient, which was equal to the sum of the GFR of a normal kidney on posterior imaging and the GFR of an ectopic kidney on anterior imaging, was compared with the total GFR (GFR_{post}) of two kidneys on posterior imaging, with the GFR in the two-sample methods ($GFR_{two-sample}$), and with the eGFR in the Chronic Kidney Disease Epidemiology Collaboration (CDK-EPI) equation. All the patients were followed up. Of 10 patients, two adult patients with obstruction of the ureteropelvic junction and severe hydronephrosis underwent pyeloplasty. The results of routine urine tests, the serum creatinine level, and the urea nitrogen level were within the normal range on follow-up. The remaining patients did not receive any therapy because of the absence of symptoms and other medical complaints. Their results of routine urine tests, the serum creatinine level, and the urea nitrogen level were always within the normal range after the diagnosis of ectopic pelvic kidneys.

Renal dynamic imaging

Renal dynamic imaging in 10 patients was completed by Hawkeye SPECT on InfiniaVC (GE Healthcare, Waukesha, Wisconsin, USA) with two typical collimators, a large field of view, and a matrix size of 64×64 . Commercial diethylenetriamine penta-acetic acid (DTPA) kits include 2.1 mg pentasodium with 0.13 mg stannous chloride dihydrate in a lyophilized form under a nitrogen atmosphere. Labeling is performed by adding free oxidant Tc-99m to the kit vial and mixing. The radiochemical purity of Tc-99m DTPA was greater than 95%. DTPA and the Mo-99/Tc-99m generator were supplied by Beijing shihong drug search center (Beijing, China) and High technology atom company Ltd (Beijing, China), respectively. All patients drank 8–10 ml/kg of

water 20–30 min before image acquisition. Their heights and weights were recorded on a data card. All patients emptied their bladders before starting the study. The patients were positioned supine, with two scintillation camera detectors placed on and under the table (anterior view and posterior view), respectively. The field of view showed both the kidneys and the bladder. A two-phase dynamic acquisition was initiated at a dose range of 111–185 MBq (3–5 mCi; a mean dose of 144.3 MBq); 3.9 mCi Tc-99m DTPA was injected according to the intravenous 'bolus' model. Phase one consisted of 60 1-s frames and phase two consisted of 20 30-s frames. Of 10 patients, two adult patients received 40 mg furosemide intravenously at the time of Tc-99m DTPA injection because of ureteropelvic junction obstruction and severe hydronephrosis.

Two-sample method

Three separate standards were prepared on the basis of the two-sample method [1] and measured under the same conditions as the injected dose of Tc-99m DTPA before renal dynamic imaging. Two blood samples (each sample 5 ml) were drawn at 120 and 240 min from the opposite forearm vein of the injection site after Tc-99m DTPA was injected. According to the procedure for blood sampling, each sample was processed immediately after withdrawal. The filtration counts of the two blood samples were tested and recorded on the basis of the procedure for ultrafiltration. $GFR_{two-sample}$ of the patients was obtained from the data using the equation of the two-sample method.

CDK-EPI equation

The serum creatinine level was measured over 2 days when renal dynamic imaging and $GFR_{two-sample}$ estimation were performed. The normal range of serum creatinine is 41–111 $\mu\text{mol/l}$ (male individuals: 57–111 $\mu\text{mol/l}$; female individuals: 41–81 $\mu\text{mol/l}$) with the enzymatic method. All the tests were performed on the same automatic biochemical analyzer (UniCel DxC 800 Synchron; Beckman Company, Brea, California, USA) in a single laboratory, and the reagents were provided by the same company that provided the machine. The CDK-EPI equation is as follows:

For female individuals with a serum creatinine concentration (Scr) of up to 62 $\mu\text{mol/l}$,

$$eGFR = 144 \times (Scr/0.7)^{-0.329} \times (0.993)^{age}.$$

For females with a serum creatinine concentration greater than 62 $\mu\text{mol/l}$,

$$eGFR = 144 \times (Scr/0.7)^{-1.209} \times (0.993)^{age}.$$

For male individuals with a serum creatinine

concentration of up to 80 $\mu\text{mol/l}$,

$$\text{eGFR} = 141 \times (\text{Scr}/0.9)^{-0.411} \times (0.993)^{\text{age}}.$$

For male individuals with a serum creatinine concentration greater than 80 $\mu\text{mol/l}$,

$$\text{eGFR} = 141 \times (\text{Scr}/0.9)^{-1.209} \times (0.993)^{\text{age}}.$$

The units for serum creatinine and age are mg/dl and years, respectively.

Processing and glomerular filtration rate

On the basis of the procedure of processing, ectopic kidney regions of interest (ROIs), normal kidney ROIs, and perirenal background ROIs were drawn manually. The data from ectopic kidneys were processed using a computer to generate renogram curves and relative uptake, and GFRs in anterior and posterior views were measured using Gates' method of renal dynamic imaging. The contralateral normal kidney was only processed by posterior imaging. The total GFR_{ant} of one patient, which was equal to the sum of the GFR of a normal kidney on posterior imaging and the GFR of an ectopic kidney on anterior imaging, was compared with the total GFR_{post} of two kidneys on posterior imaging and the $\text{GFR}_{\text{two-sample}}$ from the two-sample method. The $\text{GFR}_{\text{two-sample}}$ from the two-sample method was considered the standard value of GFR for patients with ectopic kidneys in this study.

Statistics analysis

Values are presented as mean $\pm$ SD. For comparison and agreement analysis of the GFRs from the four methods, nonparametric rank tests were used, Bland–Altman graphs were plotted, and the bias, precision, and accuracy within 30 and 10% were compared using SPSS software (version 17.0; SPSS Inc., Chicago, Illinois, USA). A *P*-value of less than 0.05 was considered significant.

Results

Comparison of the anterior and posterior view GFRs in ectopic kidneys

The data of 10 patients with ectopic pelvic kidneys were processed, and GFRs were measured using Gates' method in anterior and posterior views. The results of GFRs of ectopic kidneys in anterior and posterior views are listed in Table 1.

Comparison of total GFR_{ant} with total GFR_{post} , $\text{GFR}_{\text{two-sample}}$ from the two-sample method, and eGFR from the CDK-EPI equation

The total GFR_{ant} of one patient with an ectopic kidney was equal to the sum of the GFR of a normal kidney on posterior imaging and the GFR of an ectopic kidney on anterior imaging. The total GFR_{post} of one patient with an ectopic kidney was equal to the sum of the GFR of a normal kidney and the GFR of an ectopic kidney on

Table 1 Comparison of the measured GFRs of ectopic pelvic kidneys between anterior and posterior image processing on renal dynamic imaging (ml/min/1.73 m^2)

Number	GFR_{ant}	GFR_{post}	$\text{GFR}_{\text{ant}} - \text{GFR}_{\text{post}}$
1	10.90	4.74	6.17
2	24.44	4.24	20.20
3	41.31	15.57	25.53
4	11.24	6.20	5.04
5	40.60	16.33	24.27
6	26.38	10.82	15.56
7	35.97	9.11	26.86
8	28.15	9.45	18.7
9	41.39	16.51	24.89
10	14.41	14.11	0.29
$\bar{x} \pm S$	27.48 ± 12.24	10.71 ± 4.74	16.75 ± 9.66
<i>Z</i>		−2.803	
<i>P</i>		< 0.05	

The partial ROIs of ectopic kidneys in patients 6 and 10 overlapped with their bladder in the anterior view. The overlapped parts of ectopic kidneys with bladder in patients no. 6 and no. 10 were removed in GFR measured in anterior view. Therefore, the GFRs of ectopic pelvic kidneys measured in the anterior view were underestimated.

GFR_{ant} , GFR of the ectopic kidney on anterior image processing; GFR_{post} , GFR of the ectopic kidney on posterior image processing.

posterior imaging. Comparison and correlation analysis of total GFR_{ant} with total GFR_{post} , $\text{GFR}_{\text{two-sample}}$ from the two-sample method, and eGFR from the CDK-EPI equation in 10 patients with ectopic pelvic kidneys are shown in Tables 2 and 3 and Fig. 1a and b).

The value of serum creatinine ranged from 57.0 to 83.0 $\mu\text{mol/l}$, with a mean value of 65.20 $\mu\text{mol/l}$ and an SD of 8.19 $\mu\text{mol/l}$ in the study. The mean values of total GFR_{ant} , total GFR_{post} , total $\text{GFR}_{\text{two-sample}}$, and eGFR were 73.98 ± 18.41 , 60.90 ± 14.47 , 83.59 ± 16.63 , and 118.00 ± 23.10 , respectively. The mean value of total GFR_{ant} was closer to that of total $\text{GFR}_{\text{two-sample}}$, and these values were higher than that of total GFR_{post} .

Table 2 Comparison of the measured total GFRs of two kidneys between anterior and posterior image processing on renal dynamic imaging using the two-sample method and the CDK-EPI equation (ml/min/1.73 m^2)

Number	Total GFR_{ant}	Total GFR_{post}	Total $\text{GFR}_{\text{two-sample}}$	eGFR
1	82.24	101.24	92.00	116
2	89.45	57.37	92.30	117
3	83.61	57.83	84.00	152
4	60.84	55.80	71.00	105
5	97.40	73.53	95.00	125
6	57.00	55.14	102.00	121
7	86.03	69.05	94.00	118
8	68.84	49.92	83.70	128
9	78.41	53.54	78.00	135
10	35.93	35.62	43.90	63
$\bar{x} \pm S$	73.98 ± 18.41	60.90 ± 14.47	83.59 ± 16.63	118.00 ± 23.10
<i>Z</i>	−2.295 ^a	2.599 ^b	−2.191 ^c	−2.803
<i>P</i>	0.022 ^a	0.009 ^b	0.028 ^c	0.005 ^d

eGFR, GFR values were estimated using the CDK-EPI equation; total GFR_{ant} , sum of the GFR of a normal kidney on posterior imaging and the GFR of an ectopic kidney on anterior imaging; total GFR_{post} , total GFR of two kidneys on posterior imaging; total $\text{GFR}_{\text{two-sample}}$, total GFR of two kidneys from the two-sample method.

^aComparative analysis of total GFR_{ant} and $\text{GFR}_{\text{two-sample}}$ using the two-sample method.

^bComparative analysis of total GFR_{ant} and total GFR_{post} .

^cComparative analysis of total GFR_{post} and total $\text{GFR}_{\text{two-sample}}$.

^dComparative analysis of total GFR_{ant} and eGFR.

Table 3 Comparison of the bias, precision, and accuracy within 30 and 10% of total GFR_{ant} and total GFR_{post}

Method	Bias (mean)	Precision (SD)	Accuracy within 30% (%)	Accuracy within 10% (%)
Total GFR _{ant}	9.62	13.58	90	50
Total GFR _{post}	22.68	15.49	50	0
Value	$Z = -2.191$	$F = 0.351$		
P	0.028**	0.561*	0.062*	0.031**

Total GFR_{ant}, the sum of the GFR of a normal kidney on posterior imaging and the GFR of an ectopic kidney on anterior imaging; total GFR_{post}, total GFR of two kidneys on posterior imaging.

* $P > 0.05$ comparing the bias, precision, and accuracy of total GFR_{ant} with those of total GFR_{post}.

** $P < 0.05$ comparing the bias, precision, and accuracy of total GFR_{ant} with those of total GFR_{post}.

Fig. 1

Disagreements were present between the total GFR_{ant} and the total GFR_{two-sample}, as well as between the total GFR_{post} and the total GFR_{two-sample}. (a) Bland-Altman plot: the difference in the mean and mean total GFR_{ant} and total GFR_{two-sample} in 10 patients with an ectopic pelvic kidney. (b) Bland-Altman plot: the difference in the mean and mean total GFR_{post} and total GFR_{two-sample} in 10 patients with an ectopic pelvic kidney. Total GFR_{ant}: the sum of the GFR of the normal kidney on posterior imaging and the GFR of the ectopic kidney on anterior imaging. Total GFR_{post}: total GFR of two kidneys on posterior imaging; total GFR_{two-sample}: total GFR of two kidneys from the two-sample method.

However, Table 2 shows that there were statistical differences between total GFR_{ant} and total GFR_{two-sample} ($Z = -2.295$, $P < 0.05$), between total GFR_{ant} and total GFR_{post} ($Z = 2.599$, $P < 0.01$), between total GFR_{two-sample} and total GFR_{post} ($Z = -2.191$, $P < 0.05$), and between total GFR_{ant} and total eGFR ($Z = -2.803$, $P < 0.01$). All the eGFR values were greater than 60 ml/min/1.73 m² and higher than GFR_{two-sample}, total GFR_{post}, and total GFR_{ant}. There were also significant differences between eGFR and total GFR_{post} ($Z = -2.803$, $P < 0.01$) and between eGFR and GFR_{two-sample} ($Z = -2.805$, $P < 0.01$). These results indicate that total GFR_{ant} represents the function of the ectopic pelvic kidney more accurately than GFR_{post}.

GFR values of ectopic pelvic kidneys measured in the anterior view were closer to those measured in the posterior view in patients 6 and 10, but both their total GFR_{ant} and their total GFR_{post} were significantly lower than their total GFR_{two-sample} and eGFR. This reason was probably that the overlapped parts of ectopic kidneys with bladder in patients no. 6 and no. 10 were removed. The ectopic kidney ROIs drawn were smaller than their true ROIs in GFR measured in anterior view.

A comparison of bias, precision, and accuracy within 30 and 10% was performed between total GFR_{ant} and total GFR_{post} (Table 3). The results showed that the bias of the total GFR_{ant} was statistically different from that of the total GFR_{post} ($Z = -2.191$, $P < 0.05$). There were no differences between the precision and accuracy within 30% of total GFR_{ant} and that of total GFR_{post} (precision: $F = 0.351$, $P > 0.05$), but there were statistical differences between the accuracy within 10% of total GFR_{ant} and that of total GFR_{post} ($P < 0.05$).

Bland-Altman graphs indicated that bias and disagreement were present between total GFR_{ant} and total GFR_{two-sample}, as well as between total GFR_{post} and total GFR_{two-sample} (Fig. 1a and b).

Discussion

Ectopic kidney is a rare condition that presents in the true pelvis, iliac fossa, or lumbar or thoracic region and occurs because of an embryonic developmental anomaly [2–5]. An ectopic kidney in the true pelvis mostly results from an anomaly in the kidney position. The majority of ectopic pelvic kidneys are small in appearance and occur in cases of renal aplasia. Ectopic kidney can be complicated by hydronephrosis [6], urinary tract infection [7], and calculi [3]. Diagnosis of ectopic pelvic kidneys can be made by ultrasonography. Other imaging modalities such as renal cortical scintigraphy using ^{99m}Tc-dimercaptosuccinic acid, CT, and MRI have been shown to be useful in the diagnosis of ectopic pelvic kidneys [8–10]. It is usually discovered by chance when patients with an ectopic kidney present to the hospital for a physical examination or with other complaints.

Generally, no treatment is required for an ectopic kidney if the renal function is normal and no complications such as obstruction are found. If renal dysfunction or extensive renal damage has occurred, the ectopic kidney is often removed for the relief of symptoms. Because one or both ectopic kidneys may be located at an unusual position, there is an increased risk for the development of complications such as stone formation, urinary tract infection, and tumors [11]. Cases of renal cell carcinoma, renal tumor, and Wilm's tumor in crossed fused renal ectopia have been reported [12–16]. An ectopic kidney can even be donated for kidney transplantation when the function of the other kidney is normal. Hence, an ectopic kidney can be considered a source of transplantation kidneys [17]. Therefore, it is very important to evaluate the split renal function of both kidneys, especially the function of an ectopic pelvic kidney, by renal dynamic imaging with ^{99m}Tc -DTPA. In addition, both two-sample methods and serum creatinine–cystatin C clearance determinations with the creatinine–cystatin C equation [18,19] are more precise methods for estimation of the function of kidneys and measurement of total GFR of both kidneys; these are generally used in clinical practice. Currently, renal dynamic imaging is already being widely used in clinical practice because of some of its major advantages, such as its noninvasive nature and measurements of total and split GFRs of kidneys. However, it also has some drawbacks in terms of the measurement of the GFR of kidneys; interference factors such as 'bolus-like' injection, depth of kidneys, acquisition position, and so forth may affect the measurements. With other factors remaining unchanged, the position and depth of the kidneys (the distance of the kidneys from the skin of the abdomen and the lumbar region) are two critical factors in the measurement of the GFR of ectopic pelvic kidneys. When the kidneys are located in the usual position, renal depth correction in renal dynamic imaging can be achieved using the formula $e^{-\mu x}$ (where $\mu = 0.153$, the linear attenuation coefficient for Tc-99m radiation in soft tissues, and x = the mid-plane depth of each kidney, in cm, which can be estimated from the patient's height and weight according to the formulae of Tønnesen and colleagues [20,21]. If there is a 1 cm change in renal depth, the GFR of the split kidney will show a large difference. Therefore, in some special cases with an ectopic pelvic kidney and a transplant kidney, the position of the kidney in the abdomen determines its depth and GFR. Because the position of an ectopic pelvic kidney is closer to the skin of the abdomen rather than the skin of the lumbar region, the values of its depth estimated in the posterior view will be less accurate for GFRs measured than those estimated in the anterior view in renal dynamic imaging. As an ectopic pelvic kidney can be viewed more clearly in the anterior view, not in the posterior view, the ROI of an ectopic kidney can be drawn easily and the function of an ectopic kidney measured will be more precise in the anterior view.

Then, theoretically, the GFR of an ectopic pelvic kidney measured using Gates' method in the anterior view should be higher than that in the posterior view. Of course, calculation of renal depth by ultrasonography would be preferable as an actual measured value can be entered and used in the GFR calculations. In the present study, GFRs (27.48 ± 12.24 ml/min/ 1.73 m²) of an ectopic pelvic kidney measured in the anterior view were significantly greater than GFRs (10.71 ± 4.74 ml/min/ 1.73 m²) measured in the posterior view. The mean value of total GFR_{ant} was closer to that of total GFR_{two-sample} and eGFR. Their values were higher than those of total GFR_{post}. These results showed that GFRs measured using Gates' method in the anterior view were more precise than those measured in the posterior view and GFR of an ectopic pelvic kidney measured in the posterior view was underestimated. As the majority of ectopic pelvic kidneys are located above the bladder, they often overlap with the top portion of the full bladder. Hence, the portion of the ectopic kidney overlapping with the bladder will interfere with the construction of an ROI of the ectopic kidney and with the measurement of GFR in the anterior view. In this study, patients 6 and 10 were in this kind of situation. When the overlapping portions of ectopic kidney with the bladder were removed in drawing ectopic kidney ROIs, the ectopic kidney ROI was smaller than its true ROI. GFR of ectopic pelvic kidneys measured in anterior view were closer to that measured in posterior view in patients no. 6 and no. 10, but both their total GFR_{ant} and total GFR_{post} were significantly lower than total GFR_{two-sample} and eGFR. Therefore, when ectopic pelvic kidneys require treatment on the basis of their function, it would be preferable to measure the GFR of ectopic pelvic kidneys using Gates' method of renal dynamic imaging in the anterior view. The eGFRs were higher than the total GFR_{ant}, the total GFR_{post}, and the GFR_{two-sample}. This could have been because the serum creatinine values in nine patients were normal, and in one female patient (patient 10, serum creatinine = 83 $\mu\text{mol/l}$), the value was only slightly higher than the normal upper limit of serum creatinine in this study.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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