Article

Arch. Esp. Urol. 2023; 76(10): 802–809
https://doi.org/10.56434/j.arch.esp.urol.20237610.97

^{99m}Tc-DTPA Renal Dynamic Imaging for Evaluating the Function of Duplex Kidneys in Adult Patients

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Published: 28 December 2023

Background: This study aimed to explore technetium-99m-diethylenetriaminepentaacetic acid (^{99m}Tc-DTPA) renal dynamic imaging to evaluate duplex kidney function in adult patients.
Subjects and Methods: We retrospectively analyzed the clinical data of 25 patients with duplex kidneys who underwent ^{99m}Tc-DTPA renal dynamic imaging between June 2011 and March 2023 at our hospital. Patients in the duplex kidney group (n = 25) were divided into renogram normal (n = 9) and abnormal (n = 16) groups according to the imaging data. Additionally, normal patients were selected as the control group (n = 25). After imaging, the region of interest of the kidneys was delineated, and renography was performed. Renography can provide renal function parameters, including glomerular filtration rate (GFR), T_{max}, $T_{1/2}$, renal clearance, and the GFR ratio of the duplex renal segment (upper renal moiety).
Results: Compared with the control group, the serum creatinine level in the duplex kidney group was higher (*p* = 0.025), GFR was lower (*p* = 0.001), and patients with impaired renal function were mainly in the abnormal renography group (*p* = 0.001). In the duplex kidney group, the GFR (*p* = 0.026) and renal clearance (*p* = 0.006) of the affected kidneys were lower than those of the contralateral kidneys, and T_{max} (*p* = 0.025) was higher than that of the contralateral kidneys. There were no differences in renal function indicators of duplex renal segments with different GFR ratios. However, when the GFR ratio exceeded 50%, the renal function tended to decline.
Conclusions: ^{99m}Tc-DTPA renal dynamic imaging was found useful to evaluate the total renal function, split renal function, and upper urinary tract patency in patients with duplex kidneys. Patients with abnormal renography results had worse renal function, and those with poor renal clearance in the affected renal moiety required surgical treatment.

Keywords: duplex kidney; ^{99m}Tc-DTPA; renal dynamic imaging; renography; renal function

Introduction

The duplex kidney is a relatively common congenital urinary system malformation that is defined as a renal unit comprising two pelvicalyceal systems and two sets of collection systems in a normal kidney region on at least one side [1,2]. The incidence of duplex kidneys is 0.2%–2.0%, and most simple duplex kidneys are asymptomatic throughout life [2–4]. However, complicated duplex kidneys can lead to complications, including ectopic ureteral opening, ureteral orifice cysts, and stricture of the ureteropelvic junction, resulting in recurrent urinary tract infections, lower abdominal masses, hydronephrosis, and other clinical symptoms [5–7]. Therefore, further evaluation of renal function is important in patients with duplex kidney disease. Compared with conventional imaging methods, including B-ultrasound [8], micturating cystourethrograms (MCU), computed tomography (CT), and magnetic resonance (MR), nuclear medicine imaging focuses more on renal function evaluation [9]. Technetium-99m-diethylenetriaminepentaacetic acid (^{99m}Tc-DTPA) renal dynamic imaging can accurately determine the difference in renal function between the upper and lower moieties of duplex kidneys [10–14] and provide information on the patency of the upper urinary tract [15].

In this study, ^{99m}Tc-DTPA renal dynamic imaging was used to evaluate renal function and upper urinary patency in patients with duplex kidneys with the aim of providing a basis for the selection of treatment methods.

Table 1. Patients' characteristics.

Characteristics	Duplex kidney group (n = 25)	Control group (n = 25)	*p*
Age (year)	42.68 ± 15.58	48.08 ± 9.87	0.122
Male [n (%)]	6 (24.0)	10 (40.0)	0.230
BMI (kg/m^2)	24.90 ± 4.67	24.44 ± 3.87	0.792
Scr (μmol/L)	80.68 ± 8.15	63.32 ± 7.42	0.025
GFR (mL/min)	79.94 ± 19.30	95.26 ± 7.25	0.001

BMI, body mass index; Scr, serum creatinine; GFR, glomerular filtration rate. The normal reference range of BMI is 18.5–23.9 kg/m^2. The normal reference ranges of Scr are 54–106 μmol/L in males and 44–97 μmol/L in females. The normal reference range of GFR is ≥80 mL/min.

Subjects and Methods

Patients

A retrospective study was performed on 25 patients (19 females, 6 males; Age 42.68 ± 15.58 years) diagnosed with duplex kidney disease using B-ultrasound or abdominal CT, who underwent ^{99m}Tc-DTPA renal dynamic imaging in our hospital between June 2011 and March 2023. All patients met the following inclusion and exclusion criteria:

The inclusion criteria were as follows: Patients with a duplex kidney over 18 years of age (with or without complications such as hydronephrosis and ureteral cyst).

The exclusion criteria were as follows: Patients with other kidney diseases and those without detailed clinical data.

All 25 patients had duplex kidneys with different degrees of hydronephrosis, and all 25 duplex renal segments were in the upper renal moiety. The patients underwent blood testing after admission, and their serum creatinine (Scr) values were recorded (Table 1).

Moreover, 25 patients (15 females, 10 males; Age 48.08 ± 9.87 years) with normal ^{99m}Tc-DTPA renal dynamic imaging who needed to evaluate total and split renal function clinically were selected as the control group. In order to reduce selection bias, patients in the control group were selectively matched to those in the duplex kidney group in terms of gender ratio, age range, and visit time. Personal information has not yet been published.

Imaging Instruments and Methods

Single photon-emission computed tomography (Siemens Symbia Intevo 16, Batch No.: 10764804, Siemens Medical Solutions USA, Inc., Hoffman Estates, IL, USA) was performed. All patients drank 500 mL of water 30 min before examination. After measuring the height and weight, the patients were positioned on the examination bed and injected intravenously with a bolus of ^{99m}Tc-DTPA 185 MBq, and dynamic imaging acquisition was conducted. A low-energy collimator with an energy peak of 140 keV, window width of 20%, 64 × 64 matrix, and 1–1.5 × magnification was used for data acquisition. Dynamic imaging was performed for 31 min. The perfusion phase was first collected at 1 s/frame for 1 min, and then the functional phase was collected at 10 s/frame for 30 min. The radioactivity count of the syringe was measured before and after injection.

Image Analysis

The patients' height (cm), weight (kg), and radioactivity count of the injector before and after the examination were recorded. Both kidneys were manually delineated using regions of interest (ROIs) for the collected data (the upper renal moiety was included, Fig. 1a), and the glomerular filtration rate (GFR) and time-activity curve (TAC; Renography) were generated (Fig. 1b and Table 2). Additionally, the upper renal moiety was separately delineated (Fig. 1c,d and Table 3) to calculate the ratio of GFR in the upper renal moiety to that in the whole kidney (GFR ratio, $GFR_{upper\ renal\ moiety}/GFR_{affected\ kidney}$). Normal renography met the diagnostic criteria (Fig. 2). A unilateral GFR of less than 40 mL/min indicates renal dysfunction. Upper urinary tract obstruction was considered if T_{max} could not be obtained during the dynamic study, $T_{1/2}$ was more than 20 min, or renal clearance was less than 40% [16].

After obtaining imaging data, we divided the patients into groups according to their data characteristics. The 25 patients in the duplex kidney group were divided into the normal renography group (9 cases) and the abnormal renography group (16 cases) according to TAC shape and value. The GFR values of the two groups were statistically compared with those of the control group. Moreover, renal function indicators were compared between the affected and contralateral kidneys in the 25 patients, and the renal function indicators were also compared between the three subgroups with different GFR ratios (<30, 30%–50%, >50%) in the 25 patients.

Patient Follow-Up

The patients' clinical treatment data were obtained from the inpatient medical records system, and all patients were followed up by telephone within at least six months after the examination. The patient's condition and Scr levels were recorded.

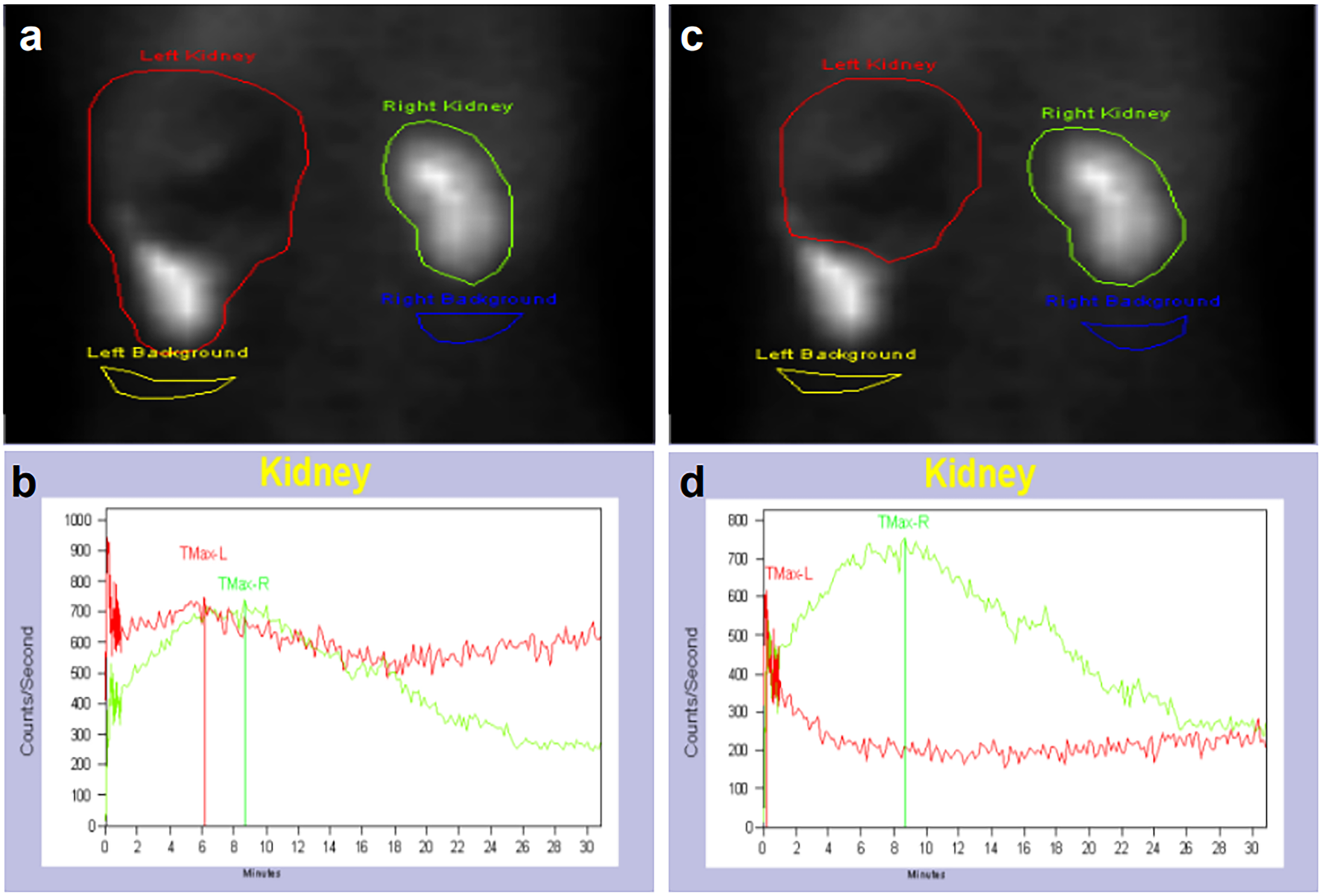

Fig. 1. Both kidneys ROI and TAC. The both whole kidneys were manually delineated as ROI (a), and the TAC was generated (b). The ROI was delineated in the upper moiety of the affected kidney and the contralateral kidney (c), and the TAC was generated (d).

Table 2. TAC data of both total kidneys.

Parameters	Left	Right	Total
Split function (%)	53.5	46.5	
Kidney counts (cpm)	84415	73412	157827
Kidney depth (cm)	4.951	4.983	
Uptake (%)	6.697	5.824	12.5
GFR (mL/min)	62.1	54.0	116.0
Normalized GFR (mL/min)			119.8
GFR low normal (mL/min)			90.0
Mean GFR (mL/min)			118.0
Renal retention	0.770	0.496	
Time of max (min)	5.468	7.969	
Time from max to 1/2 max (min)		12.0	

T_{max}, $T_{1/2}$, and renal clearance were determined by TAC. T_{max}: Time to reach peak radioactivity count in each kidney, the normal reference is $\leq$4.5 min; $T_{1/2}$: Time from peak radioactivity count to reach half its value, the normal reference is $\leq$8 min; Renal clearance: Percentage of imaging agent cleared 20 min after the acquisition, and the normal reference is $\geq$40%.

Table 3. TAC data of the upper moiety of the affected kidney and contralateral kidney.

Parameters	Left	Right	Total
Split function (%)	33.6	66.4	
Kidney counts (cpm)	36337	71863	108200
Kidney depth (cm)	4.951	4.983	
Uptake (%)	2.883	5.701	8.583
GFR (mL/min)	26.0	51.4	77.4
Normalized GFR (mL/min)			79.9
GFR low normal (mL/min)			90.0
Mean GFR (mL/min)			118.0
Renal retention	0.358	0.532	
Time of max (min)	0.033	8.519	
Time from max to 1/2 max (min)	1.597	12.1	

T_{max}, $T_{1/2}$, and renal clearance were determined by TAC. T_{max}: Time to reach peak radioactivity count in each kidney, the normal reference is $\leq$4.5 min; $T_{1/2}$: Time from peak radioactivity count to reach half its value, the normal reference is $\leq$8 min; Renal clearance: Percentage of imaging agent cleared 20 min after the acquisition, and the normal reference is $\geq$40%.

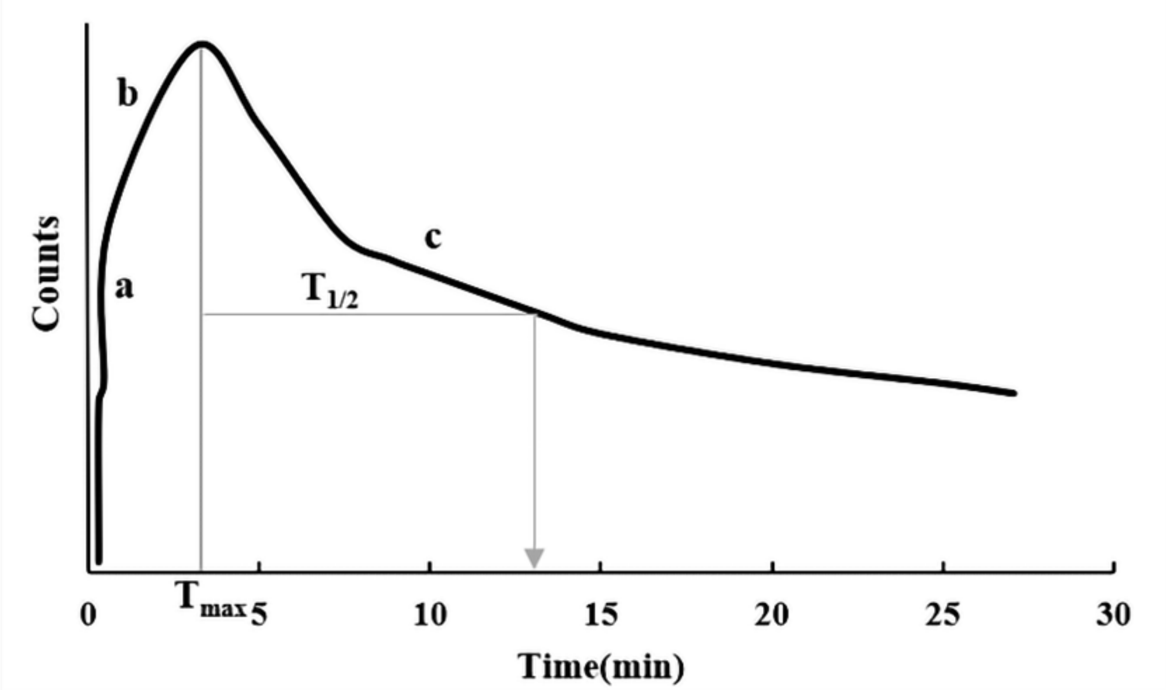

Fig. 2. Normal renography curves consist of segments a, b, and c, and the shapes and heights of the renography curves for normal kidneys are the same. Segment a: A curve rising rapidly about 10 s after intravenous injection of the imaging agent, and the time is approximately 30 s; Segment b: A curve gradually increasing after segment a, and usually reaches the peak (T_{max}); Segment c: The descending curve following segment b.

Table 4. Experimental renogram normal and abnormal group compared with the control group.

	Duplex kidney group (n = 25)		Control group (n = 25)	F	*p*
	Renogram normal (n = 9)	Renogram abnormal (n = 16)			
GFR (mL/min)	86.66 ± 16.02	76.43 ± 20.84	95.26 ± 7.25	8.297	0.001

Statistical Analysis

SPSS 22.0 software (IBM, Armonk, NY, USA) was used for statistical analysis. The data were represented as $\bar{x}$ ± s. One-way analysis of variance (ANOVA), *t*-test, least significant difference (LSD)-*t* test, and Wilcoxon signed-rank test were used, depending on whether the data were normally distributed. Categorical variable count data were expressed as percentages, and a chi-square test was performed. $p < 0.05$ was considered statistically significant.

Results

Clinical Characteristics of the Study Population

The clinical characteristics of patients in the duplex kidney and control groups are shown in Table 1. The serum creatinine (Scr) value of the duplex kidney group was higher than that of the control group ($p = 0.025$), and the total GFR of the duplex kidney group was statistically lower than that of the control group ($p = 0.001$).

Comparison of GFR between the Renogram Normal, Renogram Abnormal, and Control Groups

The differences in GFR were statistically significant between the renogram normal, renogram abnormal, and control groups ($p = 0.001$, Table 4). The LSD-*t* test showed a significant difference in GFR between the renogram abnormal and the control groups ($p < 0.001$). No significant differences were found in the GFR between the renogram normal group and the other two groups.

Comparison of the Affected and Contralateral Kidneys in the Duplex Kidney Group

There were 25 duplex kidneys in 25 patients, with 14 on the left side and 11 on the right side. The TACs were normal in 9 cases and abnormal in 16 cases, including five cases of continuous ascending TACs, five cases of parabolic TACs, and six cases of low-level prolonged TACs. T_{max} was not observed in three cases, $T_{1/2}$ was not observed in eight cases, and renal clearance was not observed in six cases. The results of the comparison of data between the affected and contralateral kidneys in the duplex kidney group are illustrated in Table 5. The GFR and renal clearance of

Table 5. Comparison between the affected and contralateral kidneys in the duplex kidney group.

	Affected kidney	n	Contralateral kidney	n	t	p
T_{max} (min)*	7.95 ± 9.48	22	3.14 ± 2.24	22	2.318	0.025
$T_{1/2}$ (min)	9.26 ± 7.11	17	12.55 ± 5.67	17	–1.494	0.145
GFR (mL/min)	34.16 ± 15.89	25	45.78 ± 19.70	25	–2.296	0.026
Renal clearance (%)	40.28 ± 16.75	19	53.61 ± 10.31	19	–2.953	0.006

*The normal reference range of T_{max} is ≤4.5 min, $T_{1/2}$ is ≤8 min, GFR is ≥80 mL/min, and renal clearance is ≥40%.

Table 6. Comparison of renal function indicators among the three groups with different GFR ratios in the upper renal moiety.

GFR ratio*	<30% (n = 3)	30%–50% (n = 8)	>50% (n = 8)	H	p
Total GFR (mL/min)	82.50 ± 22.33	89.30 ± 14.95	78.72 ± 17.26	2.164	0.339
GFR of the affected kidney (mL/min)	42.60 ± 9.00	44.86 ± 15.12	31.84 ± 13.11	3.165	0.205
T_{max} of the affected kidney (min)	8.76 ± 9.06	7.60 ± 9.60	16.17 ± 11.53	2.846	0.241
Renal clearance of the affected kidney (%)	33.47 ± 25.12	40.19 ± 18.12	37.60 ± 5.09	1.125	0.570

*GFR ratio, the ratio of the upper renal moiety GFR to that of the whole kidney ($GFR_{upper\ renal\ moiety}/GFR_{affected\ kidney}$).

Table 7. Clinical data of patients undergoing surgical treatment.

	Affected kidney				Surgical methods			Scr (μmol/L)
	T_{max} (min)	$T_{1/2}$ (min)	Renal clearance (%)	GFR (mL/min)	Upper moiety nephrectomy and ureterectomy	Ureteral J-tube implantation	Ureterocele resection	
1			53.8	18.5	+			92.2
2			21.8	50.2	+			64.3
3	19.2		4.5	42.4	+			76.8
4	2.7	6.3	63.0	26.2	+			71.9
5				17.5		+		114.4
6	30.1			43.8		+		90.7
7	28.7			34.4		+		66.9
8	22.1			24.5			+	60.6

Table 8. Comparison of Scr before and after surgery in the eight patients.

	Pre-operation (n = 8)	Postoperative (n = 8)	p
Scr (μmol/L)	79.73 ± 18.19	89.62 ± 13.57	0.434

the affected kidney were statistically lower than those of the contralateral kidney, and the T_{max} was statistically longer than that of the contralateral kidney (all $p < 0.05$). These results indicate that both the renal uptake and clearance functions of the affected kidney were impaired.

Comparison between Groups of Different GFR Ratios

Of the 25 affected kidneys in the duplex kidney group, the upper and lower moieties of the kidneys were clearly distinguished in 19 cases. In the remaining six cases, the involved kidney moieties could not be clearly delineated because of severe hydronephrosis or other reasons. In the 19 cases of duplex kidneys, there were three cases with a GFR ratio of <30%, eight cases with a GFR ratio of 30%–50%, and eight cases with a GFR ratio >50%. The indicators of affected kidneys in each GFR ratio group are shown in Table 6.

There were no statistically significant differences in the total GFR, GFR of the affected kidney, T_{max}, and 20-min clearance rate of the affected kidney among the three groups. However, compared with the GFR ratio <30% and GFR ratio 30%–50% groups, the GFR ratio >50% group had lower total GFR, lower GFR values, and longer T_{max} in the affected kidney, suggesting that renal function tended to deteriorate in the GFR ratio >50% group.

Treatment and Follow-Up

Based on ^{99m}Tc-DTPA renal dynamic imaging, surgical treatment was administered to eight patients whose clinical data are shown in Table 7. Four of these patients underwent upper moiety nephrectomy and ureterectomy, three received ureteral J-tube implantation, and one underwent ureterocele resection. The postoperative serum creatinine level was higher than the preoperative level in eight patients, although the difference was not statistically significant ($p > 0.05$, Table 8). B-ultrasound showed no complications, such as hydronephrosis or ureteral obstruction, in four patients who underwent ureteral J-tube implantation or ureteral orifice cyst resection. The patients were followed up six months after surgery, and their renal function was normal without any discomfort; Therefore, surgery was considered effective. The remaining 17 patients who did not undergo surgery received symptomatic treatment, and no discomfort was observed during the 6-month follow-up.

Discussion

Duplex kidneys have an incidence of 0.2%–2.0% [4], with a higher prevalence in women [6]. This urinary system malformation is primarily unilateral but may be bilateral [17]. Complications of duplex kidneys predominantly include hydronephrosis, ureterocele, and ureteropelvic junction obstruction [18]. GFR is the most reliable indicator of renal function, and ^{99m}Tc-DTPA is the only glomerular filtration imaging agent used for dynamic renal imaging. Conversely, for morphological examinations, including B-ultrasound and CT, and laboratory indicators, such as serum creatinine, ^{99m}Tc-DTPA renal dynamic imaging can evaluate renal function and measure total and split renal GFR [19,20]. The TAC provides information on upper urinary patency by calculating T_{max}, $T_{1/2}$, and renal clearance. Therefore, ^{99m}Tc-DTPA renal dynamic imaging is valuable for evaluating renal function and may guide clinical decision-making in patients with duplex kidneys.

Ismaili *et al.* [21] performed ^{51}chromium (^{51}Cr)-DTPA and ^{99m}Tc-mercaptoacetyltriglycine (^{99m}Tc-MAG_3) renal dynamic imaging in 44 children with duplex kidneys, and GFR was used to evaluate affected kidney function at various times. In our study, the GFR measured by ^{99m}Tc-DTPA in the duplex kidney group was lower than that in the control group, indicating that the duplex renal segment affected the total renal function and that patients with abnormal renography had worse renal function.

Liu *et al.* [22] performed ^{99m}Tc-DTPA renal dynamic imaging in seven children with duplex kidney and ureteropelvic junction obstruction and then evaluated renal function and upper urinary tract patency by GFR and $T_{1/2}$. In our research, GFR and TAC were compared between the affected and contralateral normal kidneys in the duplex kidney group, and there were no significant differences in $T_{1/2}$. However, the T_{max} of the affected kidney was significantly longer than that of the contralateral kidney, and the GFR and renal clearance of the affected kidney were significantly lower than those of the contralateral kidney, indicating that both the uptake and clearance functions were impaired in the affected kidney. Renal clearance is a sensitive indicator reflecting kidney clearance function [23]; Therefore, in duplex kidney patients with normal creatinine levels, the application of renal clearance in ^{99m}Tc-DTPA renal dynamic imaging should be considered. Notably, the $T_{1/2}$ values in the contralateral kidneys were longer than those in the affected kidneys in this study. This is because four patients had $T_{1/2}$ >15 min in the contralateral kidney, whereas their T_{max}, GFR, and renal clearance were close to or within the normal range, which may be related to individual differences in the patients and transient clearance dysfunction. For data rigor, we retained the $T_{1/2}$ values for these patients so that the $T_{1/2}$ in the contralateral kidney group was longer than that in the affected kidney group.

The GFR ratio is another indicator that reflects the renal uptake function of the affected segments in duplex kidneys [24]. A multicenter retrospective cohort study of nine years [25] studied the long-term functional renal outcomes after retroperitoneoscopic upper pole heminephrectomy for duplex kidney in children and evaluated by ^{99m}Tc-dimercaptosuccinic acid (^{99m}Tc-DMSA) scintigraphy pre- and postoperatively, the GFR ratio of ^{99m}Tc-DMSA in affected segments corresponded to the residual function. Our results showed no significant differences in total GFR, GFR of the affected kidney, T_{max}, and renal retention among the three groups with different GFR ratios in the upper renal moiety. Although no statistically significant differences were observed, the renal function was essentially normal when the GFR ratio was below 50%. The total GFR increased as the GFR ratio increased; However, when the GFR ratio was ≥50%, the total GFR, T_{max}, and renal clearance were poorer than those in the other two groups, even beyond the normal range, which might be related to the impaired renal cortex and poor upper urinary tract drainage in severely duplex kidneys.

In this investigation, eight patients underwent surgical treatment. Four patients with GFR or renal clearance and severe clinical symptoms underwent an upper renal moiety nephrectomy and ureterectomy. Renal clearance data could not be obtained for the other four patients, which indicated severely impaired renal clearance function or upper urinary tract obstruction. Based on the patient's clinical condition and assessments of renal dynamic imaging, three patients underwent ureteral J-tube implantation, and one patient underwent ureterocele cyst resection. All patients were asymptomatic and had normal renal function six months after surgery. Based on the above analysis, clinical treatment options could be combined with a comprehensive assessment of the patient's age, clinical symptoms, TAC indicators, and GFR ratio of the affected segment to the entire kidney. Different intervention methods can be used depending on the degree of renal impairment. When patients with severe hydronephrosis and recurrent urinary tract infections have decreased renal function, which seriously affects their quality of life, the preferred surgical methods are upper moiety nephrectomy and urethrectomy. If the patient's clearance function is severely impaired, but the GFR remains normal or only slightly reduced, relief of obstruction is prioritized [26].

This study had some limitations. The small number of cases researched and, inevitably, confounding factors may have affected the accuracy of the results. The number of included cases should be increased in future investigations. In this study, ROI was not performed for two distinct moieties of the affected kidney because the upper moiety's function, which determines the therapeutic method of the patient, was of greater concern.

Conclusions

^{99m}Tc-DTPA renal dynamic imaging can be used to evaluate the total and split renal function and upper urinary tract patency in patients with duplex kidney disease. Total renal function was decreased in patients with complicated duplex kidneys, and the affected kidney's function was lower than that in the contralateral normal kidney. Patients with abnormal renography had worse renal function, and those with poor renal clearance in the affected renal moiety should receive timely surgical treatment. ^{99m}Tc-DTPA renal dynamic imaging is an important method for diagnosing and guiding the treatment of duplex kidneys.

Availability of Data and Materials

All data included in this study are available and can be requested by contacting the corresponding author.

Author Contributions

XL—manuscript writing (original draft), and data collection and sorting; XMY—revision of original draft, and data collection and sorting; XRY, YN and YC—revision of the manuscript, and data analysis and statistics; MC—reviewing and revising the manuscript, financial support and responsible for all aspects of work; SL—checking the manuscript and final approval of the version to be published. All authors discussed the results and confirmed the final manuscript.

Ethics Approval and Consent to Participate

This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the Ethics Committee of Shanxi Provincial People's Hospital (China) (Ethics: 2021-KY-230). The requirement for informed consent from the participants was waived due to the retrospective nature of this study.

Acknowledgment

Not applicable.

Funding

The research was funded by the China Postdoctoral Science Foundation (2020M670704) and Fundamental Research Program of Shanxi Province (202103021224377).

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Li Y, Yu M, Tan L, Xue S, Du X, Wang C, *et al*. Disruption of Gen1 causes ectopic budding and kidney hypoplasia in mice. Biochemical and Biophysical Research Communications. 2022; 589: 173–179.

[2] Kozlov VM, Schedl A. Duplex kidney formation: developmental mechanisms and genetic predisposition. F1000Research. 2020; 9: F1000 Faculty Rev-2.

[3] Doery AJ, Ang E, Ditchfield MR. Duplex kidney: not just a drooping lily. Journal of Medical Imaging and Radiation Oncology. 2015; 59: 149–153.

[4] Privett JTJ, Jeans WD, Roylance J. The incidence and importance of renal duplication. Clinical Radiology. 1976; 27: 521–530.

[5] Hunziker M, Kutasy B, D'Asta F, Puri P. Urinary tract anomalies associated with high grade primary vesicoureteral reflux. Pediatric Surgery International. 2012; 28: 201–204.

[6] Davda S, Vohra A. Adult duplex kidneys: an important differential diagnosis in patients with abdominal cysts. JRSM Short Reports. 2013; 4: 13.

[7] Potenta SE, D'Agostino R, Sternberg KM, Tatsumi K, Perusse K. CT Urography for Evaluation of the Ureter. Radiographics: A Review Publication of the Radiological Society of North America, Inc. 2015; 35: 709–726.

[8] Liu X, Sun J, Liu F. Ultrasonography of complete duplex ureter with paraurethral ectopic opening of the upper kidney ureter. International Urogynecology Journal. 2022; 33: 1037–1039.

[9] Momin MA, Abdullah MNA, Reza MS. Comparison of relative renal functions calculated with ^{99m}Tc-DTPA and ^{99m}Tc-DMSA for kidney patients of wide age ranges. Physica Medica. 2018; 45: 99–105.

[10] Li N, Li B, Liang W, Zhao D. Comparison of glomerular filtration rate measured between anterior and posterior image processing using Gates' method in an ectopic pelvic kidney. Nuclear Medicine Communications. 2016; 37: 519–524.

[11] Cheng MH, Zeng FW, Xie LJ, Li JF, Zhang F, Jiang H. A new quantitative method for estimating glomerular filtration rate and its clinical value. Clinical Physiology and Functional Imaging. 2016; 36: 118–125.

[12] Cichocki P, Filipczak K, Surma M, Płachcińska A, Kuśmierek J. Application of normalized values of kidney clearance function in the diagnosis of bilateral obstructive nephropathy—a preliminary report. Nuclear Medicine Review. Central & Eastern Europe. 2018; 21: 92–95.

[13] Wang C, Gao C, Maimaiti W, Li S, Yang Q, Jiang L. The features of technetium-99m-DTPA renal dynamic imaging after severe unilateral ureteral obstruction in adult rabbits. PLoS One. 2020; 15: e0237443.

[14] Pang X, Li F, Huang S, Wang C, Zhang T, Hu Z, *et al*. A Novel Method for Accurate Quantification of Split Glomerular Filtration Rate Using Combination of Tc-99m-DTPA Renal Dynamic Imaging and Its Plasma Clearance. Disease Markers. 2021; 2021: 6643586.

[15] Simal CJR. ^{99m}Tc-DTPA Diuretic Renography with 3 hours late output fraction in the evaluation of hydronephrosis in children. International Braz J Urol: Official Journal of the Brazilian Society of Urology. 2018; 44: 577–584.

[16] Jain V, Arora S, Passah A, Mani K, Yadav DK, Goel P, *et al*. Comparison of the renal dynamic scan performed with ^{99m}Tc-L, L-EC and ^{99m}Tc-MAG3 in children with pelviureteric junc-

tion obstruction. Nuclear Medicine Communications. 2018; 39: 1053–1058.
[17] Williams H. Renal revision: from lobulation to duplication—what is normal? Archives of Disease in Childhood. Education and Practice Edition. 2007; 92: ep152–158.
[18] Yener S, Pehlivanoğlu C, Akis Yıldız Z, Ilce HT, Ilce Z. Duplex Kidney Anomalies and Associated Pathologies in Children: a Single-Center Retrospective Review. Cureus. 2022; 14: e25777.
[19] Taylor AT. Radionuclides in Nephrourology, Part 2: Pitfalls and Diagnostic Applications. Journal of Nuclear Medicine. 2014; 55: 786–798.
[20] Taylor AT. Radionuclides in Nephrourology, Part 1: Radiopharmaceuticals, Quality Control, and Quantitative Indices. Journal of Nuclear Medicine. 2014; 55: 608–615.
[21] Ismaili K, Hall M, Ham H, Piepsz A. Evolution of Individual Renal Function in Children with Unilateral Complex Renal Duplication. The Journal of Pediatrics. 2005; 147: 208–212.
[22] Liu W, Zhang L, Ma R, Wu R. The morphology and treatment of coexisting ureteropelvic junction obstruction in lower moiety of duplex kidney. International Journal of Surgery. 2016; 34: 23–27.
[23] Cheuiche AV, Queiroz M, Azeredo-da-Silva ALF, Silveiro SP. Performance of Cystatin C-Based Equations for Estimation of Glomerular Filtration Rate in Diabetes Patients: A Prisma-Compliant Systematic Review and Meta-Analysis. Scientific Reports. 2019; 9: 1418.
[24] Kwatra N, Shalaby-Rana E, Majd M. Scintigraphic features of duplex kidneys on DMSA renal cortical scans. Pediatric Radiology. 2013; 43: 1204–1212.
[25] Joyeux L, Lacreuse I, Schneider A, Moog R, Borgnon J, Lopez M, *et al*. Long-term functional renal outcomes after retroperitoneoscopic upper pole heminephrectomy for duplex kidney in children: a multicenter cohort study. Surgical Endoscopy. 2017; 31: 1241–1249.
[26] Mantica G, Paraboschi I, Farneti F, Kalpana P, Tagizadeh A, Anu P, *et al*. Surgical management of complicated duplex kidney: a tertiary referral centre 10-year experience. African Journal of Paediatric Surgery. 2023; 20: 51–58.