



Morphologic and functional evaluation of duplicated renal collecting systems with MR urography: A descriptive analysis



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ABSTRACT

Purpose: To describe the morphology and function of duplicated collecting systems in pediatric patients undergoing functional MR urography (fMRU).

Methods: This is a HIPAA compliant IRB approved retrospective study of all patients with duplicated renal collecting systems undergoing fMRU at our institution between 2010 and 2017. Two pediatric radiologists evaluated the studies to determine the presence, morphology and function of duplicated collecting systems using both T2-weighted and dynamic post-contrast fat saturated T1-weighted images. Assessed morphologic features included pelvic and calyceal dilation, partial or complete ureteral duplication, ureteral dilation, ectopic ureteral insertion and ureteroceles. Functional analysis was carried out per moiety.

Results: A total of 86 examinations (63 girls; 23 boys), median age 2.6 years (Standard Deviation 6.4 years, interquartile range: 0.4–10.3 years) and 107 kidneys (39 right; 30 left and 19 bilateral), which yielded 214 evaluable moieties, were included in the final sample. One hundred and sixty-three (76.1%) of the moieties had normal morphological features and normal functional results (average calyceal transit time and renal transit time of 2 min 28 s and 3 min 16 s, respectively). The remaining 51 moieties (23.8%) were hypoplastic or dysplastic. Seventy-seven (35.9%) had pelvic and calyceal dilation. Slightly more than half of the kidneys had complete ureteral duplication (60/107; 56%); 50 (50/107, 46.7%) had ectopic ureters (23 intra- and 27 extravesical) and 9 (9/107, 8.4%) had ureteroceles.

Conclusion: fMRU provides comprehensive information regarding the morphology and function of duplicated renal collecting systems in children. In particular, fMRU is useful for assessing barely or non-functioning renal poles and ectopic ureters.

1. Introduction

Duplicated renal collecting systems, which indicate that the kidney divided during embryogenesis into separate upper and lower pole sections (moieties) with or without separate duplicated ureters, are commonly encountered congenital anomalies of the urinary tract [1,2]. The exact prevalence is difficult to ascertain as it represents a normal variant in most patients and is most frequently detected incidentally on imaging performed for other indications. In general, it is estimated that complete or incomplete ureteral duplication occurs in 1 in 125 (0.8%) [1]; while higher incidences (2%–8%) are reported in children presenting with urinary tract symptoms [3,4]. Bilateral collecting system

duplication occurs in 20%–40% of affected individuals [2–4].

Functional magnetic resonance urography (fMRU) provides a comprehensive morphological and functional evaluation of the urinary tract in a radiation-free, single examination with excellent spatial, contrast and rapid temporal resolution [5–11]. fMRU is gaining popularity particularly if complex anatomy is inadequately characterized by ultrasound [10–16]. Morphologic information is depicted best on T2-weighted images while dynamic scanning after intravenous injection of a gadolinium chelate contrast agent yields important functional information including perfusion, concentration, and excretion of the contrast agent in both the renal cortex and medulla [5]. Studies comparing fMRU with scintigraphy have shown high concordance of the

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two methods [8,17–22].

In cases of duplex collecting systems, fMRU can help differentiate functioning from barely or non-functioning renal poles, and provide information for the calculation of differential renal function [5–11]. Furthermore, it depicts ectopic ureters, allows better delineation of each moiety in complicated duplex systems and helps surgical planning. We describe the morphology and function of duplicated collecting systems in pediatric patients undergoing functional MR urography (fMRU).

2. Materials and methods

This is a HIPAA-complaint retrospective study of all patients with duplicated collecting systems that underwent fMRU at our hospital between July 2010 and September 2017. The study was approved by our Institutional Review Board. The electronic medical records of these patients were reviewed for relevant demographic and clinical data. In particular, patients that have undergone heminephrectomy and/or ureteral reimplantation were excluded. All studies in the final sample with a duplicated collecting system were then anonymized for subsequent review. The main clinical indication for fMRU was obtained by comparing the history provided for the study to the most recent urology note and categorized as: i) urinary tract dilatation by prior ultrasound (including pelvocaliectasis, hydronephrosis, UPJ obstruction and UVJ obstruction), ii) abnormal (asymptomatic at the time of MRU) prior imaging (including: megaureter, ureterocele, ectopic ureter, MCDK, focal lesion, stones, or vesicoureteral reflux) or iii) symptoms not explained by ultrasound (including: flank pain, hematuria, incontinence, urinary tract infection).

2.1. Image acquisition

All patients were hydrated with 15 ml per kg of intravenous normal saline (maximum 1000 ml) over 1 h prior to the procedure. Intravenous furosemide (Lasix®, Sanofi-Aventis, Paris, France) 1 mg per kilogram (maximum dose 40 mg) was routinely administered at the beginning of the examination. This allowed optimal distention and thus improved visualization of the urinary tract, evaluation of excretory function under diuresis, minimization of T2 star artifacts on postcontrast fMRU, and shortened examination time. We routinely used urinary bladder catheterization to reduce the potential negative effect of a distended bladder on renal contrast material excretion, to decrease confounding effects from possible high-grade vesicoureteral reflux, and to avoid disruption of the examination from increased urgency of voiding in non-sedated patients. Patient sedation, provided by anesthesiologists, was used as per usual clinical indications with most patients between 6 months to 6 years of age requiring sedation or anesthesia.

The field of view of the fMRU is from above the upper poles of the kidneys through to the perineum. The protocol starts with sagittal T2-weighted half-Fourier (SSFSE/HASTE) images that are used to plan an oblique coronal plane angled parallel to the long axis of the kidneys, encompassing the ureters and bladder. Additional sequences include axial T2-weighted images with fat saturation, coronal T2-weighted images with fat-saturation, coronal 3D heavily T2-weighted images with fat saturation, as well as dynamic 3D T1 GRE images with fat saturation before and after intravenous administration of gadolinium contrast agent (Table 1). However, the exact imaging protocol was modified over the study period with the elimination of coronal T1, post-contrast sagittal T1-w images as well as shortening of the postcontrast coronal 3D T1-weighted images from 16 min to 8 min starting in 2015; while making the prone positioning optional.

The standard gadolinium contrast dose was 0.1 mmol/kg (0.2 ml/kg; minimum 2 ml, maximum 20 ml) gadopentetate dimeglumine (Magnevist®, Bayer HealthCare Pharmaceuticals Inc., Whippany NJ) until November 2015 or gadoterate meglumine (Dotarem®, Guerbet LLC, Princeton, NJ) thereafter with a dose of 0.1 mmol/kg (0.2 ml/kg;

minimum 1 ml, maximum 20 ml). A power injector with an injection rate of 0.1–0.25 ml per second was used to ensure a linear relationship between signal intensity and contrast concentration that is needed for the Patlak equation calculations.

All exams were supervised in real-time by a pediatric radiologist and depending on the extent of the contrast washout, delayed images including scanning in prone position were performed up to 45 min after contrast administration with additional sequences added ad hoc in real time.

2.2. Imaging analysis

Two-pediatric radiologists with special interest in genitourinary imaging and seven (***) and five (***) years of experience reviewed each moiety on fMRU images for morphology and function in consensus, blinded to clinical data and other urologic imaging. Morphological features of both renal moieties were described using standardized terminology as per the recommendations from the Committee on Terminology, Nomenclature, and Classification of the Section on Urology of the American Academy of Pediatrics [23], as follows: Duplex kidney refers to a single renal parenchymal unit that is drained by two pelvicalyceal systems; Upper (or lower) pole represents the components of a duplex kidney; A duplex system can be associated with a bifid ureter (partial/incomplete ureteric duplication), which refers to two ureters that join before draining into the urinary bladder, or complete ureteral duplication, when the two ureters drain separately into the urinary bladder (intravesical) or outside of it (extravesical). Upper pole ureter and lower pole ureter drain the upper pole and lower pole, respectively, of a duplex kidney. Upper pole or lower pole orifice refers to the orifice in the bladder associated with the ureter draining the upper or lower pole respectively. An ectopic intravesical ureter is either a caudal ectopic ureter, where the ureter inserts medial and inferior to the normal position of the trigone, or a cranial ectopic ureter, where the ureteral orifice inserts on the bladder lateral to the normal position. A ureterocele is a cystic dilation of the intravesical submucosal distal ureter. Ureteroceles contained entirely within the bladder are classified as intravesical ureteroceles, whereas ectopic (extravesical) ureteroceles contain a portion permanently situated at the bladder neck or in the urethra. The degree of urinary tract (pelvic and calyceal) dilation were graded as normal (pelvic diameter < 10 mm), pelvic and calyceal dilation (pelvic diameter between 10 and 15 mm and central calyceal dilatation), or severe pelvic and calyceal dilation (pelvic diameter of > 15 mm and central and peripheral calycectasis). Ureteral dilation and tortuosity was also recorded. Duplex kidneys (two renal pelvic and calyceal systems) that drain into a single ureter at the ureteropelvic junction and those associated with a fusion anomaly (i.e. either crossed fused ectopia or horseshoe configuration) were excluded.

Functional evaluation was carried out by using publically available free post-processing software (www.chop-fmru.com) [24]. Routinely obtained functional parameters included: calyceal transit time (CTT), renal transit time (RTT), and differential renal functions (DRF). The calyceal transit time (CTT) is the time lapse between the contrast arrives in the aorta until it reaches the calices; while the renal transit time (RTT) is the time needed for the contrast to reach the ureter (below the level of the lower pole of the kidney) [24]. The CTT is a useful measurement of function as the contrast passage through the kidney is delayed in poorly functioning moieties and in those with distal obstruction (either at the UPJ or UVJ). RTT helps differentiate obstructed systems (i.e.; RTT > 8 min) from those systems (dilated or not) that are not critically obstructed (< 4 min) [25]. The DRF (also known as split renal function) is expressed for each moiety as a percentage of the total renal function. DRF can be calculated as the percentage based on the volume of enhancing renal parenchyma (vDRF), the Patlak numbers, which are a functional parameter per unit tissue (pDRF), or a combination thereof (vpDRF). The combination (vpDRF) is particularly useful in cases in which large kidneys have low Patlak numbers or vice versa,

Table 1
Basic MR urography protocol.

	2D localizers	Half-Fourier single shot TSE	T2-w TSE	T2-w 2D TSE	T2-w 3D urogram	T1-w 3D GRE dynamic Gd
Plane	3 planes	Sagittal	Axial	Coronal	Coronal	Coronal
Fat saturation	No	Yes	Yes	Yes	Yes	Yes
Respiratory compensation	No	No	No	No	Triggered	No
Number of slices	3 + 3 + 3	40	30	30	60	32
Slice thickness	10 mm	3 mm	3 mm	3 mm	1 mm	2 mm
Field of view	450 mm	220 mm	160 mm	220 mm	220 mm	280 mm
Matrix	256 × 256	256 × 256	320 × 320	256 × 256	256 × 256	256 × 256
TR	15	1100	6000	6000	1800	3.6
TE	5	100	145	102	600	1.2
Flip angle	40	177	150	102	170	30
Receiver bandwidth	180 mHz	476 mHz	140 mHz	201 mHz	476 mHz	650 mHz
Turbo factor		150	23	13	121	
Parallel acquisition tech	No	No	No	No	GRAPPA*	GRAPPA*
Imaging time (s)	15	40	360	156	250	10 (4800)

* GeneRalized Autocalibrating Partial Parallel Acquisition.

small kidneys importantly contributing to the renal function. For accurate functional analysis of duplex kidneys, each moiety is segmented separately.

When available, fMRU findings were compared to the most recent ultrasound to determine if the configuration of the duplex system was known at the time of initial clinical interpretation of fMRU.

2.3. Statistical analysis

Descriptive analysis of categorical variables is presented as counts and percentages. A chi-square test (or Fisher exact, when appropriate) was used to examine differences between incidence of dysplasia, pelvic and calyceal dilation and ureterectasis in the upper versus lower pole moieties. A *p*-value < 0.05 was considered significant. Statistical analysis was performed by using SPSS version 23 (IBM, Armonk, NY) software.

3. Results

From 701 fMRU studies performed in the study period, 86 (12.2%) cases were included in the final sample (Table 2). The median age of these 86 patients (63 girls; 23 boys; F:M ratio 2.7:1), was 2.6 years (Standard Deviation 6.4 years, interquartile ratio-IQR: 0.4–10.3 years) and included 107 kidneys (39 right; 30 left and 19 bilateral), with 214 evaluable moieties. 60.4% (n = 52/86) presented for further evaluation of urinary tract dilatation in prior imaging; 24.4% (n = 21/86) presented with prior abnormal imaging findings; and 15.1% (n = 13/86) presented with symptoms that require additional imaging evaluation.

One hundred and sixty three (76.1%, 163/214) moieties had normal morphologic features and normal functional results (average calyceal transit time-CTT- and renal transit time-RTT- of 2 min 28 s and 3 min 16 s, respectively). The differential renal function in these normal moieties was 38%. The remaining 51 moieties (23.8%, 51/214) had hypoplastic or dysplastic features. Abnormal features are significantly more common in the upper pole moieties (*p* < 0.001) (Fig. 1) with only 10% of lower pole moieties showing abnormal morphology features (Fig. 2). A comparison between morphologic features of the upper and lower pole moieties is provided in Table 3. The morphologically abnormal moieties showed significantly lower functional results (average CTT and RTT of 4 min 08 s and 4 min 52 s, respectively). The differential renal function in the abnormal moieties averaged 10.5%. Average functional values including calyceal and renal transit times as well as differential renal functions in upper versus lower renal moieties are provided in Table 4.

Seventy-seven (35.9%, 77/214) moieties, had pelvic dilation with 31 (31/77, 40.3%) cases of pelvic dilation between 10 mm and 15 mm and the remaining 46 (46/77, 59.7%) moieties showing pelvic dilation

Table 2
Basic characteristics of the sample and those with ectopic ureteral insertion.

	Sample	Ectopic ureters
Patients characteristics		
Sample size (patients)	86 (100%)	42 (48.8%)
Age (median (IQR))	2.6 (0.4–10.3 years)	1.01 (0.3–4.3) years
Gender		
Female	73.3% (63/86)	73.8% (31/42)
Male	26.7% (23/86)	22.2% (11/42)
Clinical indication		
Urinary tract dilatation ^a	60.4% (52/86)	52.4% (22/42)
Abnormal imaging finding ^b	24.4% (21/86)	33.3% (14/42)
Clinical symptoms ^c	15.1% (13/86)	14.3% (6/42)
Moiety descriptors		
Renal parenchymal morphology		
Normal	46% (163/214)	36% (18/50)
Dysplastic	24% (51/214)	64% (32/50)
Pelvic dilatation		
< 10 mm	66% (141/214)	38% (19/50)
10–15 mm	14% (31/214)	28% (14/50)
> 15 mm	20% (42/214)	34% (17/50)
Ureter morphology		
Normal	63% (134/214)	24% (12/50)
Mild tortuosity	15% (32/214)	18% (9/50)
Marked tortuosity	22% (48/214)	54% (29/50)
Functional parameters ^d		
Calyceal transit time in seconds (median (IQR))	149 (119–186)	198 (139–315)
Renal transit time in seconds (median (IQR))	178 (147.5–221.8)	229.5 (155.8–379.5)
Differential renal function (% of total)	22% (15.1%–40.1%)	6.6% (2.7%–32.4%)

^a Urinary tract dilatation by prior ultrasound: antenatal pelvocaliectasis, hydronephrosis, UPJ obstruction and UVJ obstruction.

^b Abnormal (asymptomatic at the time of MRU) prior imaging: megaureter, ureterocele, ectopic ureter, MCDK, focal lesion, stones, vesicoureteral reflux.

^c Symptoms not explained by ultrasound: flank pain, hematuria, incontinence, urinary tract infection.

^d Functional parameters are calculated only for functioning moieties. Nonfunctioning moieties are hence excluded.

of > 15 mm (Fig. 3). The presence and degree of urinary tract dilation was not significantly different between upper and lower pole moieties (*p* = 0.09). Dilatation and tortuosity of the ureter was significantly more common in the upper moieties (*p* < 0.001).

A configuration suggesting UPJ obstruction was seen in 9 cases, 6 lower and 3 upper moieties. Ureteral tortuosity was more common and severe in the upper pole moieties compared to the lower pole moieties (*p* < 0.001). More than half (60/107; 56%) of the kidneys had complete ureteral duplication; 50 (50/107, 46.7%) kidneys had ectopic ureters (23 intra- and 27 extravesical) (Figs. 3 and 4); while in the

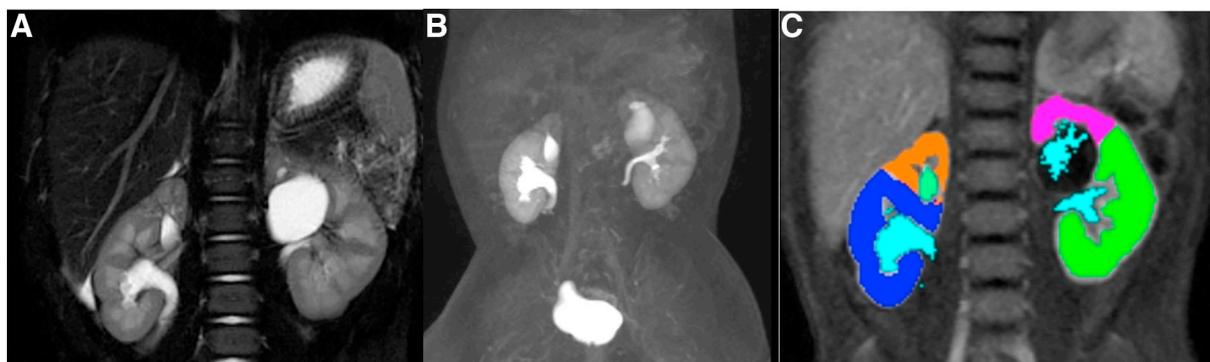


Fig. 1. 11 month old girl with bilateral duplicated collecting systems. (a) Coronal T2-weighted (TR: 5500/TE: 100) shows bilateral duplicated collecting systems with left upper moiety dilatation. (b) Coronal MIP 4 min post contrast injection-T1-weight imaging with fat saturation (TR: 3.6/TE: 1.5) shows excretion of contrast from both kidneys but delayed in the left upper moiety. (c) Coronal MIP from functional analysis data shows the segmentation of each moiety (right upper: orange, right lower: blue, left upper: pink, left lower: green, and secreted contrast from the collecting systems: turquoise). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

remaining 10 (10/107, 9.3%), there was midureter atresia or both bladder openings were so close that it was impossible to ascertain ectopia.

The 50 ectopic ureters included in the current study correspond to 42 (42/86, 48.8%) patients with a median age of 1 year (Standard Deviation: 5 years, IQR 0.27–4.0 years). Ectopic ureters were more common in girls (31/42, 73.8%) than in boys (11/42, 22.2%). In these patients, the right kidney alone was affected in eighteen subjects (18/42, 42.8%), the left kidney alone in sixteen (16/42, 38.1%) and the remaining 8 (8/42, 19.1%) had bilateral ectopic ureters. The extra-vesical ureters, 21 in girls and 6 in boys, had vaginal (13/27, 48.1%) (Fig. 2), urethral (12/27, 44.4%), and ejaculatory duct/seminal vesicle (2/27, 7.4%) insertions. All ectopic ureters originated from the upper moiety.

An ultrasound was available for comparison in all but two cases (84/86, 97.6%), and in 105 kidneys (105/107, 98.1%). Ultrasound correctly identified the duplex system in 69 of the cases (69/86, 80%) and in 85 individual kidneys (85/107, 79.4%); including four cases in which a duplex system was identified unilaterally failing to recognize it in the contralateral kidney. Of the 22 kidneys with duplex collecting system not identified by ultrasound, 19 (19/22, 86.3%) had normal parenchymal appearance and 20 (20/22, 90%) were not dilated neither at ultrasound nor fMRU; Twelve (12/22, 54.5%) of these duplex kidneys had partially duplicated ureters and the remaining 10 (10/22, 45.4%) had complete ureteral duplication. Importantly, ultrasound was unable to identify four extra-vesical ectopic ureters in this group (two with vaginal and two with urethral insertion).

4. Discussion

We found a higher incidence of duplicated collecting systems (12%) than previously reported for asymptomatic (0.8%) or symptomatic children (2–8%). This result is somewhat expected as fMRU depicts higher anatomic detail and allows increased identification of the additional renal moieties even when highly dysplastic and/or non-functioning. The important advantageous ability of fMRU to demonstrate severely dysplastic moieties with no or little function is a result of the natural contrast provided by urine on pre-contrast T2-weighted images [10,11,26–28]. However, it is also true that patients with complex anatomy or uncommon symptoms are more likely to be referred for fMRU, introducing selection bias. Furthermore, even in this selected and often symptomatic population, the great majority of the duplicated systems represent a normal variant with normal appearance and function. In these cases, the main value of fMRU remains the combined functional assessment. In the remaining cases, in which there are parenchymal and/or functional anomalies, fMRU offers the ability

to detect superimposed urologic pathology and provides function in a by-moiety detail. fMRU also helps surgical planning for duplex renal systems and a thorough assessment of the quality of the parenchyma in each moiety [28–30]. In the past, many severely dysplastic kidneys were identified only at time of surgery [29]. Moreover, details on function might help surgeons decide between interventions with salvage of the moieties, heminephrectomies or nephrectomies. In a previous series, out of 8 patients with duplicated systems undergoing laparoscopic heminephrectomies, only one had functional confirmation of poor function; while in the remaining 7 function was assumed poor from parenchymal thinning in anatomic cross-sectional imaging [31]. Details on function can also help determine the timing of intervention because declining function might predate parenchymal loss and scarring in non-dilated systems such as those with reflux.

We find fMRU also to be useful in the evaluation of patients with duplex kidneys and suspected ectopic ureteral insertions or occult or dysplastic upper poles, whom might present with flank pain, hypertension, or paradoxical incontinence [32]. In fact, the main diagnosis missed by US was the presence of ectopic ureters. Moreover, in our cohort, ectopic ureters were diagnosed at fMRU with a median age of 1 year and 75% diagnosed before 3 years of age, which is before the average age to gain bladder control. These patients have an advantage in terms of early diagnosis and prompt treatment that can avoid additional urinary tract infections with further damage to the parenchyma as well as costs and consequences related to delay toilet training including delayed schooling and repeated consultations for incontinence. Potential preservation of renal function at an early age is also an advantaged in boys with ureteral ectopia, because they do not present with incontinence or urinary “dribbling”.

Findings of female predominance (almost 3:1) and bilaterality in 20% of patients, validate previous literature reports [2–4,27]. This validation is of importance because much of the recent literature regarding duplex renal systems is limited to reviews [10,11,33] and case reports [34–41]. Similarly, our findings are in keeping with well-known understanding of the renal development with upper moieties more commonly showing pelviectasis, ureterectasis and dysplasia as well as being the origin of all ectopic ureters, known as the Weigert–Meyer rule [11]. UPJ obstruction was more common in the lower moieties, which is also well known. However, it is important to highlight that in our series one third (3 of 9) occurred in the upper pole, a fact previously reported but rarely acknowledged in the literature [42].

Regarding function, our results also aligned with previous experience from nuclear medicine renal function studies, in which both the calyceal and renal transit times (CTT and RTT) were delayed in renal moieties with dysplastic features. Similarly, moieties with renal pelvic dilation and tortuous ureters showed longer renal transit times, which is

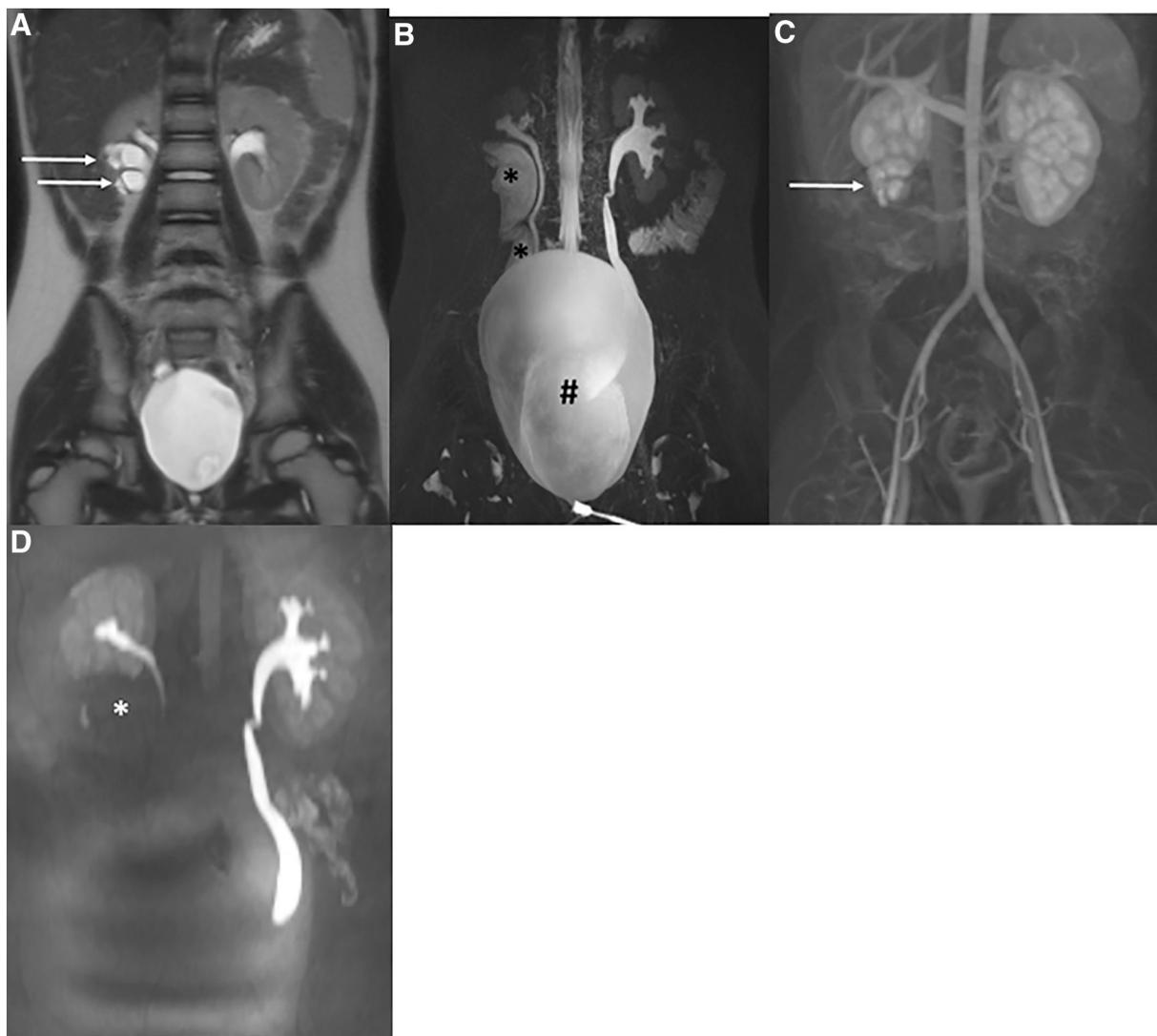


Fig. 2. 6 year old boy with history of recurrent urinary tract infections and bilateral reflux (high grade reflux into the lower moiety of a duplicated right collecting system). Of note, the patient and parents requested no bladder catheterization, explaining the markedly dilated urinary bladder in the later images. (a) Coronal T2 weighted image (TR: 900; TE: 95) shows dilatation of the right lower pole collecting system with associated cortical thinning (arrows). (b) Maximum intensity projection (MIP) image from heavily T2-weighted imaging with fat saturation (TR: 3150/TE: 650) shows marked dilatation of the right lower moiety pelvis and proximal ureter (*) as well as a distended bladder (#). (c) Maximum intensity projection (MIP) image from post contrast T1-weight imaging with fat saturation (TR: 3.6/TE: 1.1) shows enhancement of the atrophic lower pole moiety (arrow). However, (d) 8-minute delayed maximum intensity projection (MIP) image from post contrast T1-weight imaging with fat saturation (TR: 3.6/TE: 1.1) shows no significant amount of contrast in the right lower moiety collecting system (*) due to poor function and the confounding dilution from reflux in this patient without a decompressing bladder catheter.

Table 3
Morphologic MR urography (fMRU) findings.

Morphologic assessment		Upper pole moiety	Lower pole moiety	Total (moieties)	<i>p</i> *
Renal parenchymal morphology	Normal	63% (67/107)	90% (96/107)	46% (163/214)	< 0.001
	Dysplastic	37% (40/107)	10% (11/107)	24% (51/214)	
Pelvic dilation	< 10 mm	59% (63/107)	73% (78/107)	66% (141/214)	0.19
	10–15 mm	18% (19/107)	11% (12/107)	14% (31/214)	
	> 15 mm	23% (25/107)	16% (17/107)	20% (42/214)	
Ureter duplication	Partial		41% (44/107)	41% (44/107)	0.085
	Complete		59% (63/107)	59% (63/107)	
Ureter morphology	Normal	50% (54/107)	75% (80/107)	63% (134/214)	< 0.001
	Mild tortuosity	16% (17/107)	14% (15/107)	15% (32/214)	
	Marked tortuosity	34% (36/107)	11% (12/107)	22% (48/214)	
Ectopic ureter	Intravesical		46% (23/50)	46% (23/50)	0.42
	Extravesical		54% (27/50)	54% (27/50)	
Ureterocele			8.4% (9/107)	8.4% (9/107)	

Significant (*p* < 0.05) results in bold.

* *p* values refer to results of chi-square of upper poles compared to lower poles.

Table 4
Split renal function and transit times for duplex renal poles on functional magnetic resonance urography (fMRU).^a

		CTT (in seconds)		RTT (in seconds)		DRF (%)	
		Upper pole	Lower pole	Upper pole	Lower pole	Upper pole	Lower pole
Renal parenchyma	Normal	177.5	149.6	216.9	186.2	37.8	38.1
	Dysplastic	262.1	196.7	289.1	301.9	10.2	11.7
Renal pelvis	Not dilated (< 10 mm)	185.5	151.7	210.9	171.4	37.3	31.3
	10–15 mm dilation	191.7	152.6	300.0	242.2	21.1	20.0
	> 15 mm dilation	241.8	163.8	206.0 ^b	268.5	12.5	19.3
Ureter caliber	Normal ureter	187.0	150.2	212.2	182.3	33.6	37.2
	Mild tortuosity	177.2	145.8	288.3	238.4	27.0	30.8
	Severe tortuosity	232.4	171.6	202.5	242.7	18.2	25.8
Ectopic ureter	Intravesical	245.1	155.7	250.5	194.3	9.3	36.2
	Extravesical	200.6	143.5	214.8	189.7	26.4	41.9

CTT = calyceal transit time; RTT = renal transit time; TTP = time to peak; DRF = differential renal functioning.

^a Functional parameters are only available for functioning moieties. Accordingly, CTT is available for more moieties than RTT, as in those moieties with marked pelvocalyceal dilatation and those with UPJ obstruction, the contrast does not clear the upper ureter.

^b Only 2 out of 20 upper pole moieties with pelvocalyceal dilatation > 15 mm clear the contrast beyond the lower pole of the kidney during the image acquisition time, artifactually lowering the expected RTT.

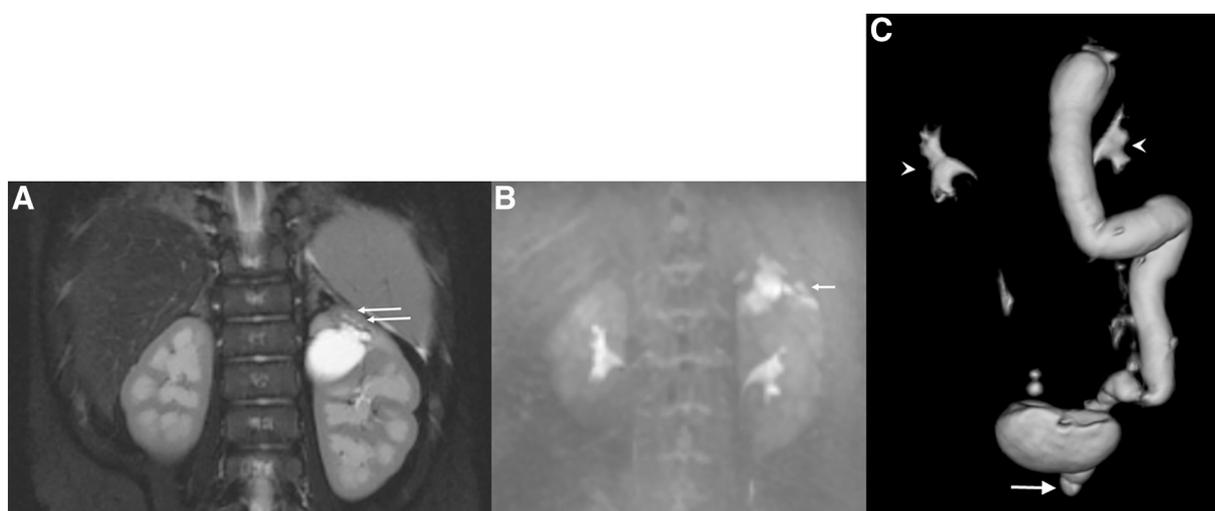


Fig. 3. 6 month old girl with a duplicated left collecting system and left upper moiety pelvocaliectasis. (a) Coronal T2 weighted image (TR: 6000; TE: 100) shows dilatation of the left upper pole collecting system with associated cortical thinning and tiny parenchymal cysts (arrows). (b) Maximum intensity projection (MIP) image from post contrast T1-weight imaging with fat saturation (TR: 3.6/TE: 1) shows delayed parenchymal enhancement 10 min after contrast injection (arrow) while the left lower moiety and right kidney already show excretion with minimal residual enhancement (left upper pole calyceal transit time of 7 min 15 s versus 2 min 9 s for the lower pole and right kidney). (c) Volume rendered image from heavily T2-weighted images (TR: 5500; TE: 700) better depicts the entire severely dilated and tortuous duplicated left upper pole moiety ureter, which inserts below the level of the bladder (arrow). The normal right and left lower moiety collecting systems (arrowheads) are also shown but the ureters are only partially visualized in this water sensitive image.

expected because the contrast would take longer to clear a dilated patulous system and reach the upper ureter. However, because moieties with little or no function are not amenable to functional analysis the CTT and RTT differences are not as pronounced as one might expect.

Our study has several limitations, mainly its retrospective nature and lack of comparison to gold standard anatomic (surgicopathological findings) and functional (nuclear medicine renal scans) techniques. However, because duplicated systems are mainly incidental, most cases lack additional evaluation and do not require surgical intervention. Another related important limitation is the selection of the sample. Because only those patients requiring additional non-invasive evaluation are referred to fMRU, some of the results might be skewed. Primarily, the incidence of duplicated systems in our sample is probably inflated and similarly, the incidence of ectopic ureters, which might be associated to other urologic abnormalities. This sampling bias is likely related to the urologists' reliance on fMRU for surgical planning at our institution, which might be a local phenomenon, not translatable to other hospitals or settings with limited access to fMRU equipment or expertise. However, all additional findings are likely valid as we

provided the anatomic description of a large sample size that helps refine the details of these common anatomic anomalies. An additional limitation is related to the technique itself, while fMRU advantages compared to nuclear medicine functional studies, including the lack of radiation and improved anatomic characterization, make fMRU a superior option, its comparison against ultrasound is more complicated because ultrasound is more widely available, it is less invasive (i.e. does not require urethral catheterization or intravenous access), and does not require sedation/anesthesia. While fMRU presents little risk to the patient, there are risks associated to sedation and anesthesia [43]. However, recent data have found that < 1 h of general anesthesia in early infancy does not alter neurodevelopmental outcome at age 5 years compared with awake-regional anesthesia [44]. Moreover, recent reports have documented a high success rate of MRU using a “feed-and-sleep” technique in patients under 10 months of age, which might significantly decreased the need for sedation in these patients if the urologic anomalies requiring further evaluation are identified before that age [45]. Last, and probably more important, our study is only descriptive and provides no definitive evidence of the added value of

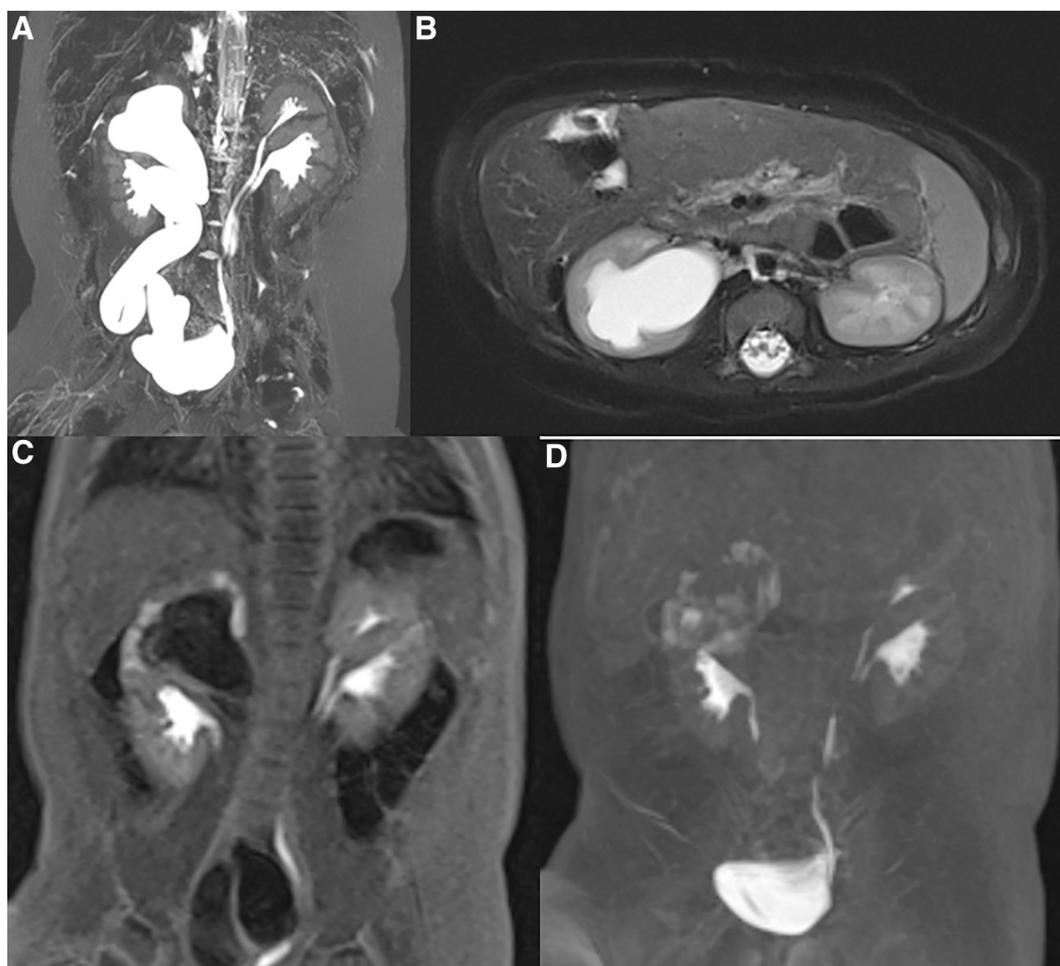


Fig. 4. 3 month old boy with prenatal diagnosis of right hydronephrosis and postnatal ultrasound with bilateral duplicated collecting systems. (a) MIP (15 mm slab) from heavily T2-weighted images (TR: 5500; TE: 700) depicts severe right upper moiety pelvocaliectasis and ureterectasis, which extends into the pelvis with an ectopic insertion into the prostatic urethra. (not shown). (b) Axial T2-weighted (TR: 5000; TE: 100) image better shows the degree of pelvicaliectasis (18 mm transverse diameter) and caliceal dilatation. (c) Coronal post contrast T1-weighted imaging with fat saturation (TR: 3.6/TE: 1) and (d) Coronal MIP image from the same postcontrast sequence show significantly delayed nephrogram right upper pole moiety with no significant contrast excretion into the collecting system at 8 min, consistent with obstruction.

fMRU, as we did not prove that the additional information directly translates into surgical management changes or improved patients outcomes. Future research will need to prove fMRU benefits in a longitudinal cohort with appropriate follow up.

5. Conclusion

In conclusion, fMRU provides comprehensive information regarding the morphology and function of duplicated renal collecting systems in children, which in our sample were more common than previously reported. While the majority of duplex renal collecting systems have normal morphologic appearance and function, they also encompass a heterogeneous group of urologic abnormalities that can be further evaluated with a single imaging examination. In particular, fMRU is useful for assessing the associated urologic abnormalities including barely or non-functioning renal poles and ectopic ureters, which can be diagnosed before they become symptomatic or result in further kidney damage.

Declaration of Competing Interest

No conflict of interest to report.

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