Pediatric Renal & Urinary Imaging

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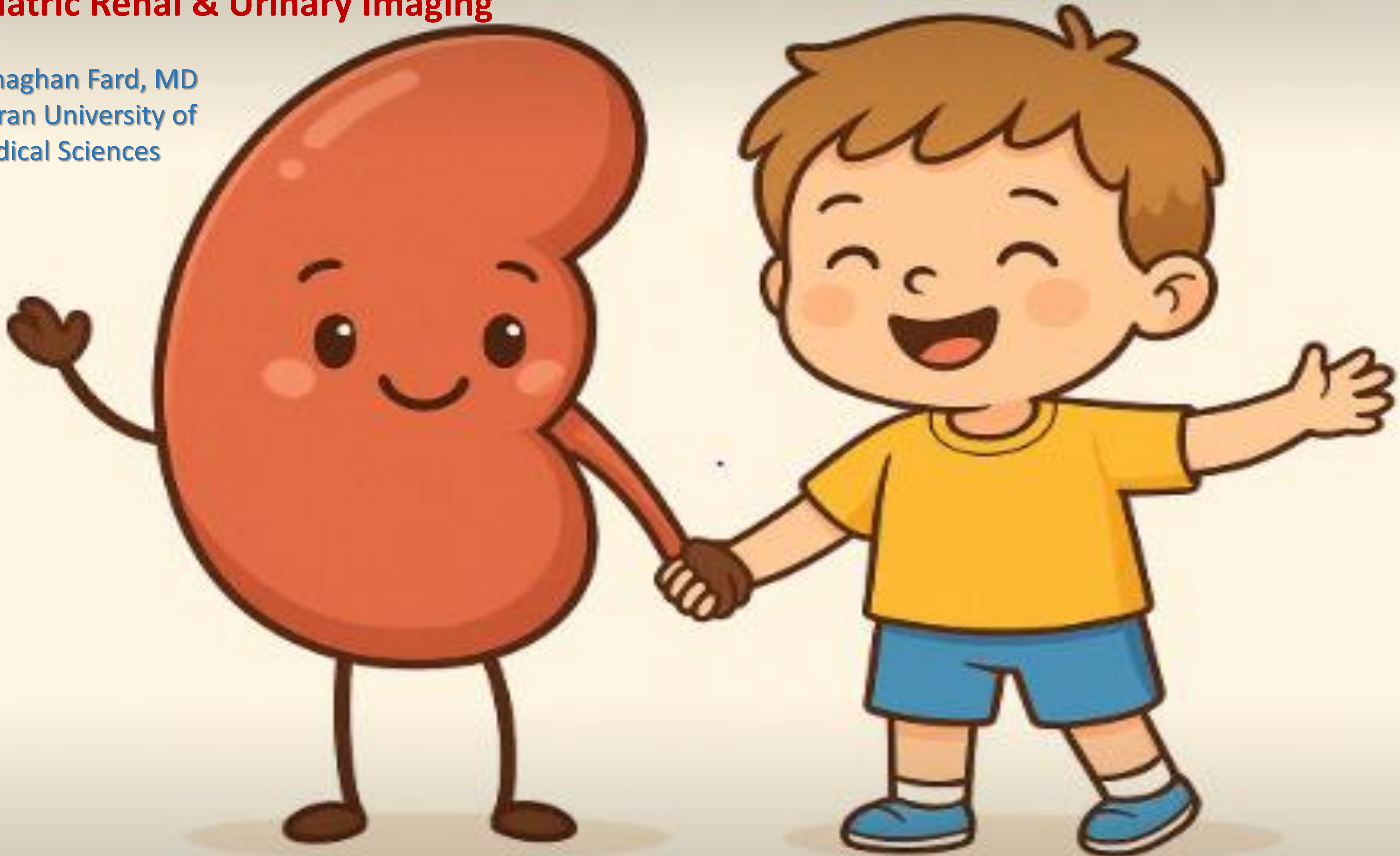
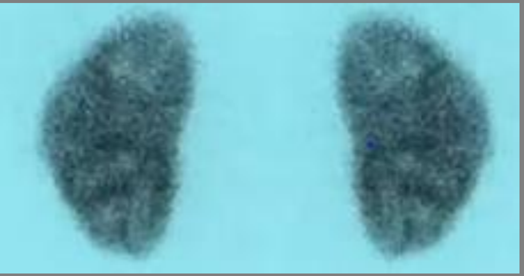


CME

Continuous Medical Education



A few PET scan urinary tract cases

PET scan can be useful in renal tumors, including Wilms, RCC, lymphoma and sarcomas, TCC, for:

Staging

Restaging

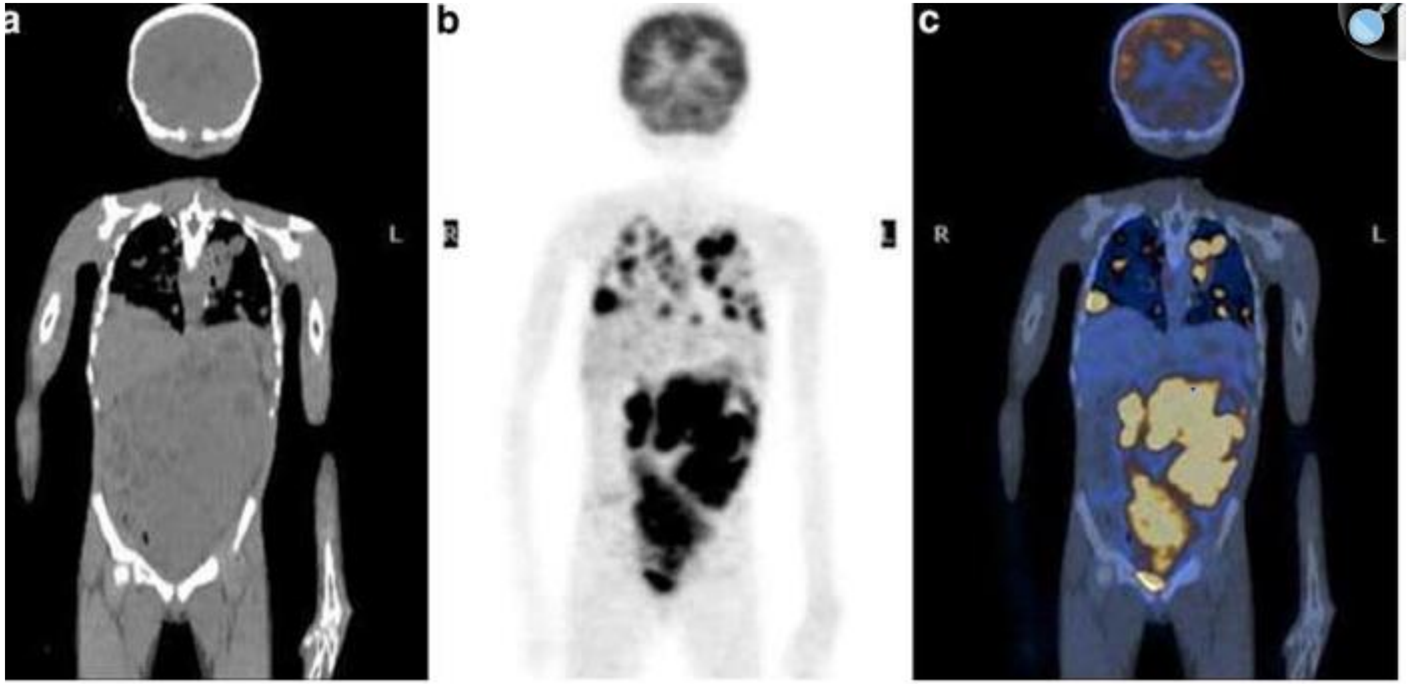
Response to therapy assessment

Wilm’s Tumor

- Most common renal tumor in children, comprising 6% of all pediatric malignancies.
- Age: < 8, average: 2-4 y/o
- Abdominal swelling, often toward one side.
- Mostly occurs in just one kidney. But it can sometimes be in both kidneys at the same time.

Wilm's Tumor

7-year-old girl with right-sided Wilms' tumor, showing extensive metastatic disease in the chest, abdomen, and pelvis



Renal Cell Carcinoma (RCC)

Renal cell carcinoma (RCC) is the second most common renal tumor in children.

RCC is rare in young children, mostly in children older than 10 years.

It can also occur in patients with *von Hippel-Lindau disease* and *Tuberous Sclerosis Complex*, or *after treatment for previous malignancies* (f.e Neuroblastoma or Leukemia)

Renal Cell Carcinoma (RCC)

F-18 FDG PET scan:

RCC can be

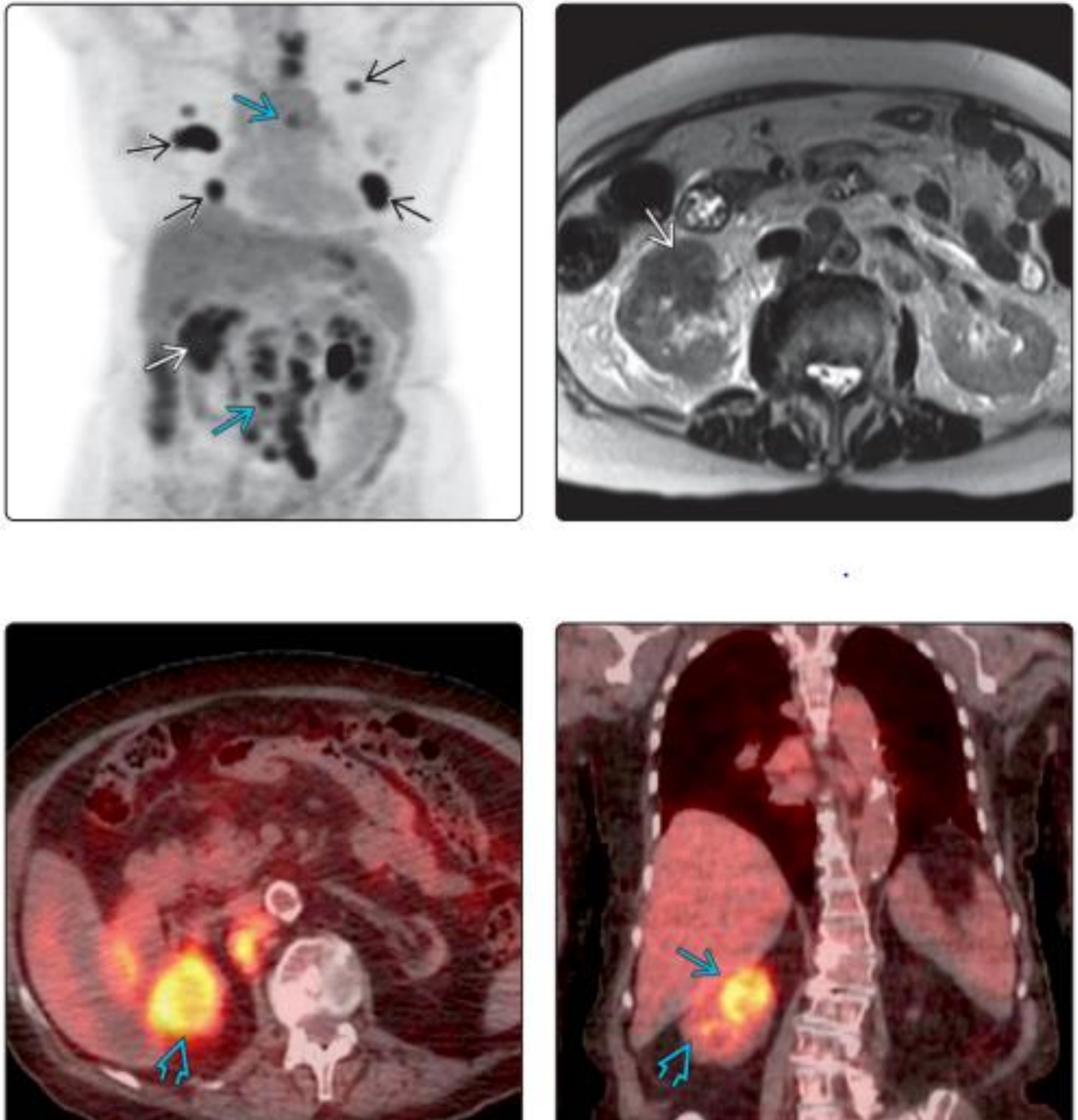
hypermetabolic to non-FDG-avid

Sensitivity 62%, Specificity 88%

RCC

Hypermetabolic RCC in the right kidney ,

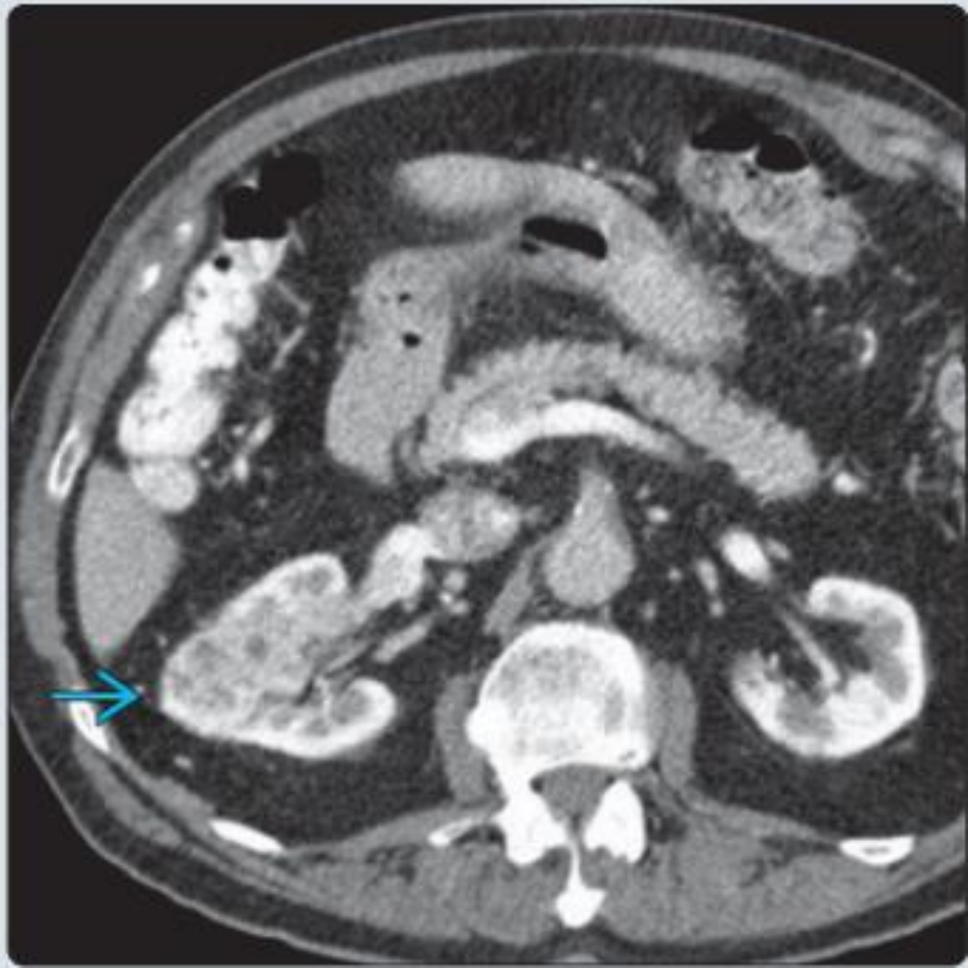
with distant metastases



RCC

An exophytic renal mass:

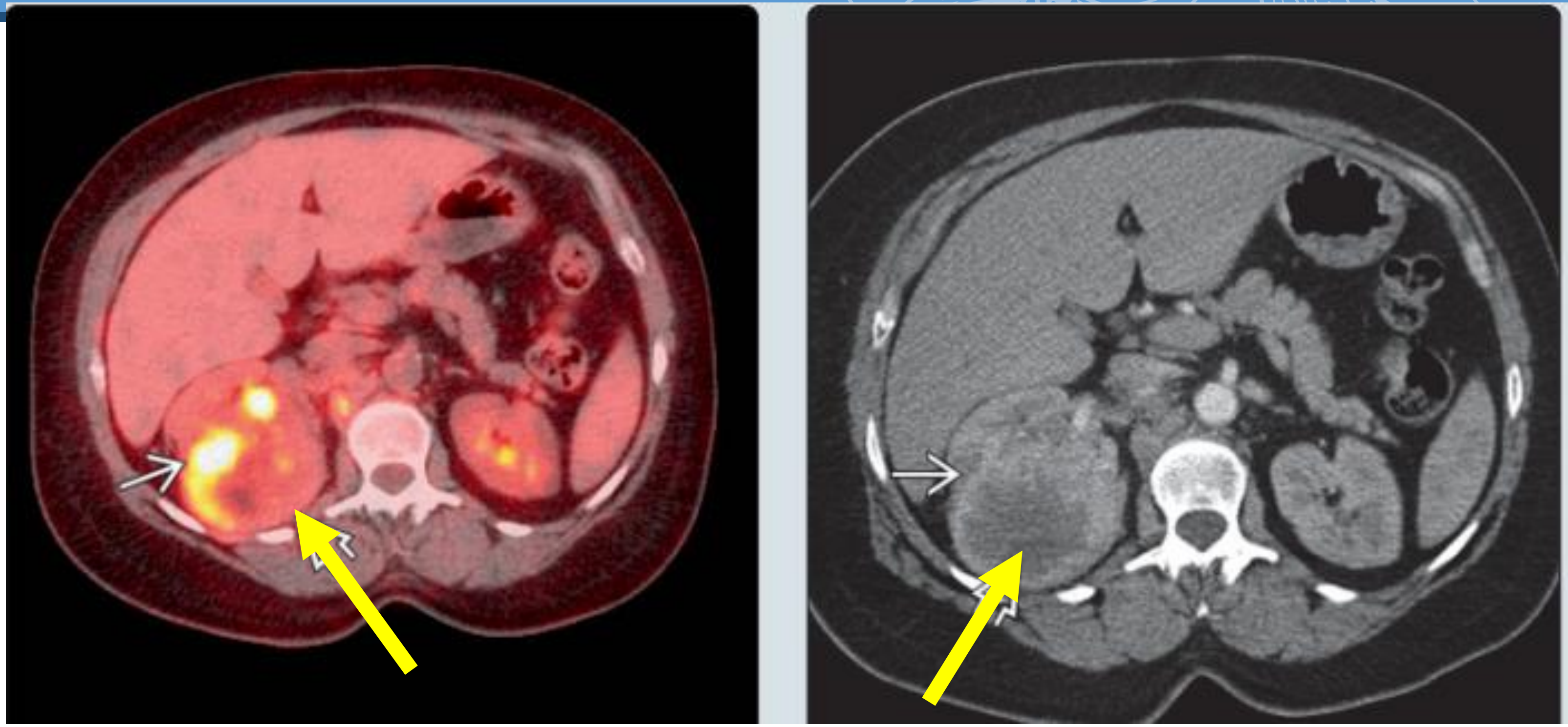
non-FDG-avid RCC



RCC

PET: areas of increased metabolic activity, which are actually urinary F-18 FDG excretion, adjacent to RCC.

CT: large, ill-defined right renal mass, with areas of central necrosis.



Transitional Cell Carcinoma (TCC)= Urothelial carcinoma

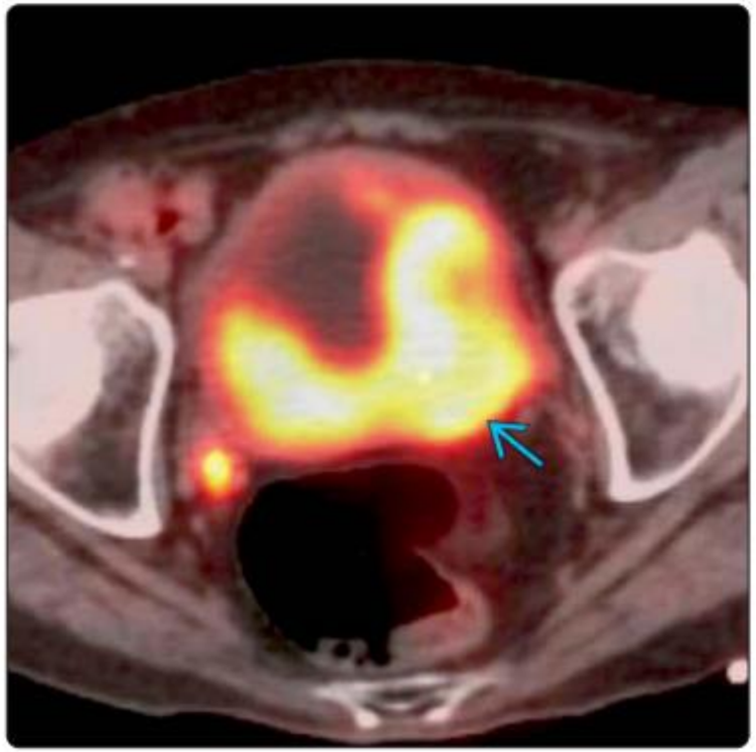
Rare in children

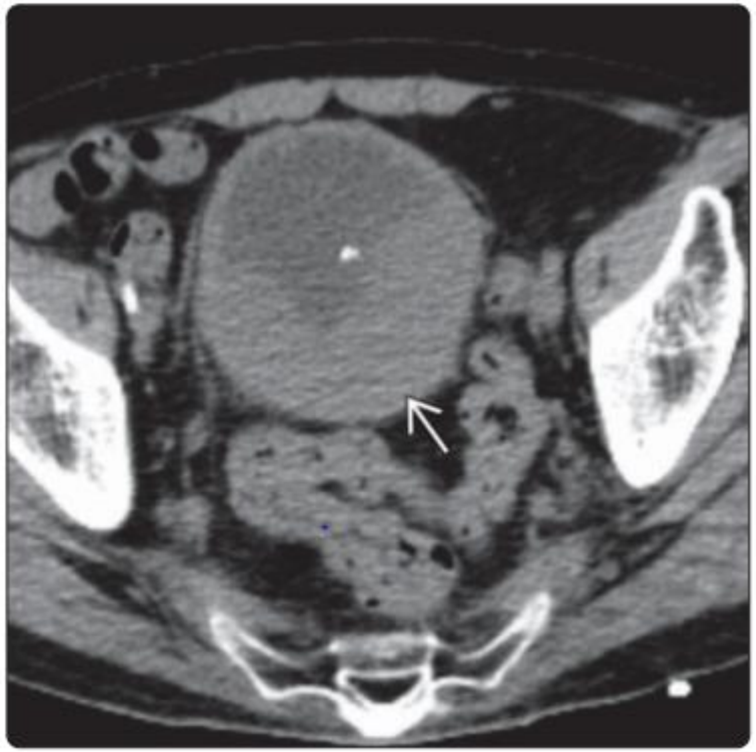
F-18 FDG PET/CT:

a large, hypermetabolic bladder mass along the posterior bladder wall.

CT:

prominent eccentric bladder wall thickening, compatible with known malignancy.





In FDG-PET scans for urinary tumors points to remember:

- **Use Diuretic**
- **Urinary bladder catheterization**
- **Always reduce the PET-portion intensity in reviewing images**
- **Always look at CT only portion**
- **Can start imaging thigh upward in bladder cancer, like prostate cancer, before bladder is refilled.**

Conventional Nuclear Medicine in:

Pediatric Renal & Urinary Imaging

Nuclear Medicine Studies in Pediatric Urology

- **Dynamic Scintigraphy / Renogram: Tc-99m MAG3, Tc-99m EC,**

  Tc-99m DTPA if tubular agents unavailable

  with or without diuretics

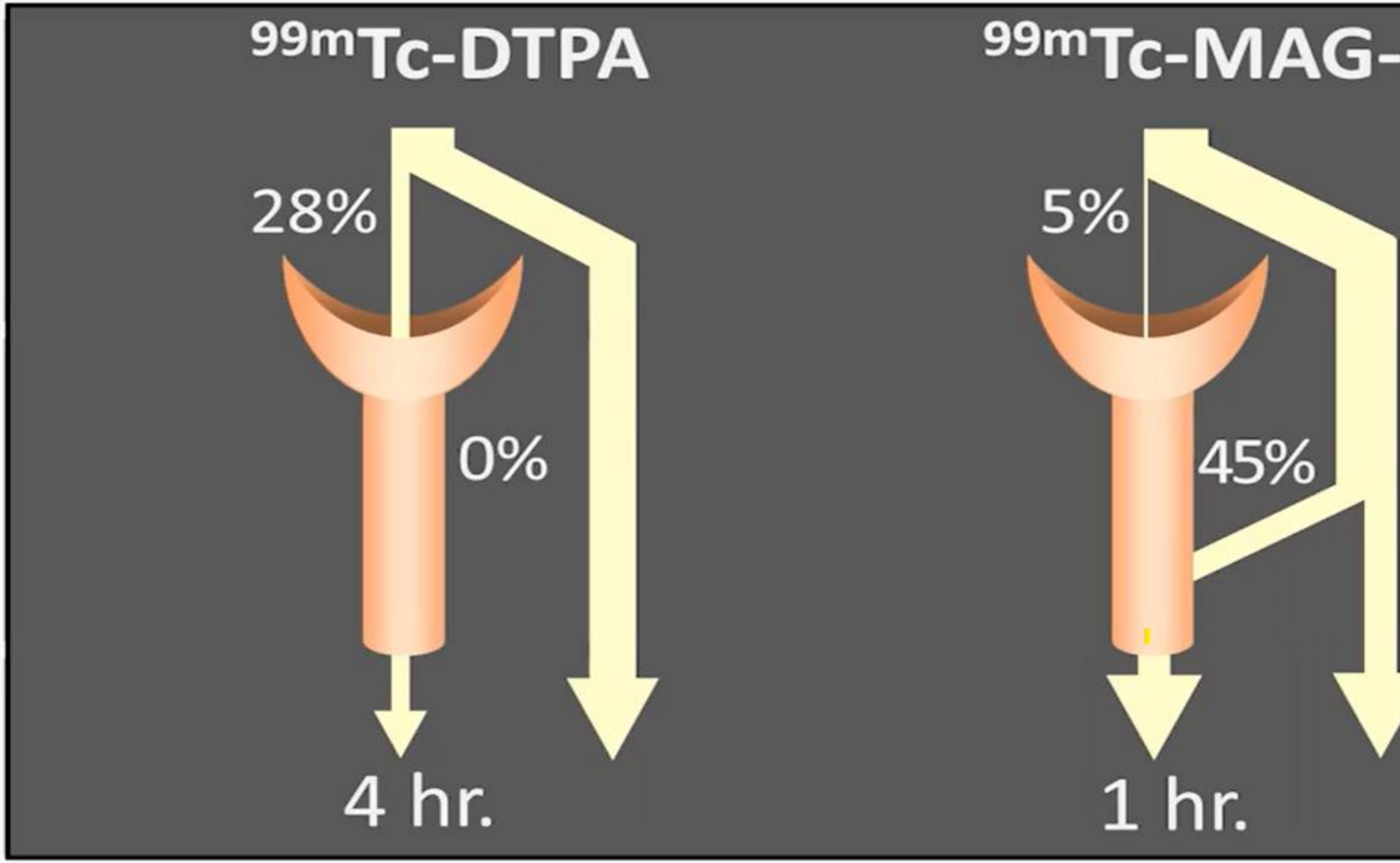
- **Renal Cortical Scintigraphy: Tc-99m DMSA**
- **Radionuclide Cystography (RNC): Tc-99m pertechnetate/SC**
- **Glomerular Filtration Rate (GFR): Tc-99m DTPA**

Dynamic Scintigraphy / Renogram:

Tc-99m MAG3, Tc-99m EC,

Tc-99m DTPA if tubular agents unavailable

Renal Extraction and Excretion of ^{99m}Tc Radiopharmaceuticals



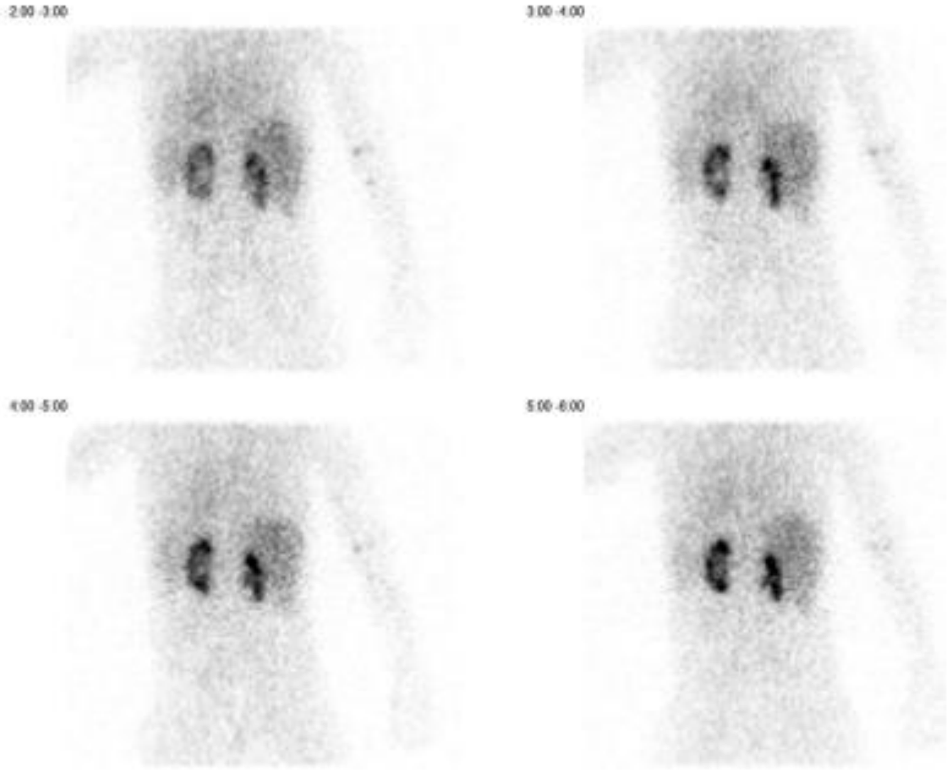
ideal for DRF estimation and indirect cystography in children

Tc-99m MercaptoAcetylTriglycine (MAG3)

- **The most commonly used renal radiopharmaceutical**
- **Cleared almost entirely by tubular secretion**
- **High Extraction efficiency (40-50%), more than twice that of DTPA**
- **Significant anatomical detail, while assessing function**
- **The alternative path of excretion: Hepatobiliary**

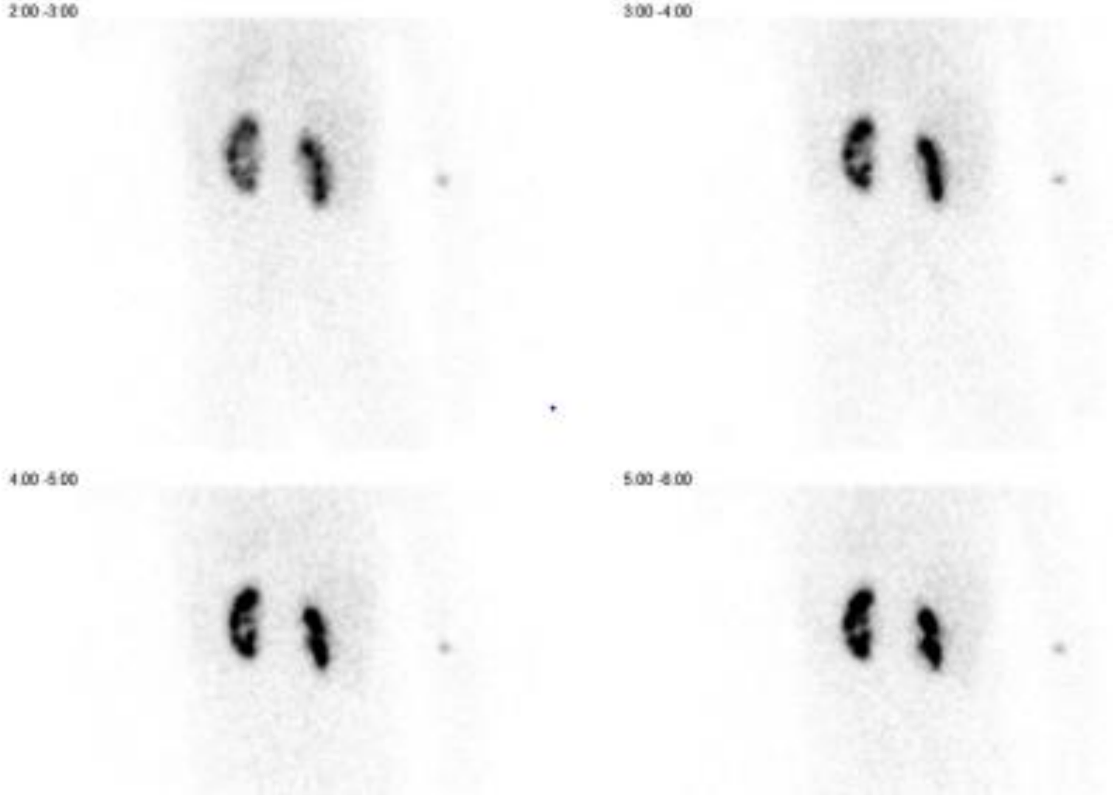
Tc-99m MAG3 study:

Known left kidney obstruction.
Discussion on normal right kidney
Pitfall: high background and liver uptake on first exam, results in false underestimation of renal function.



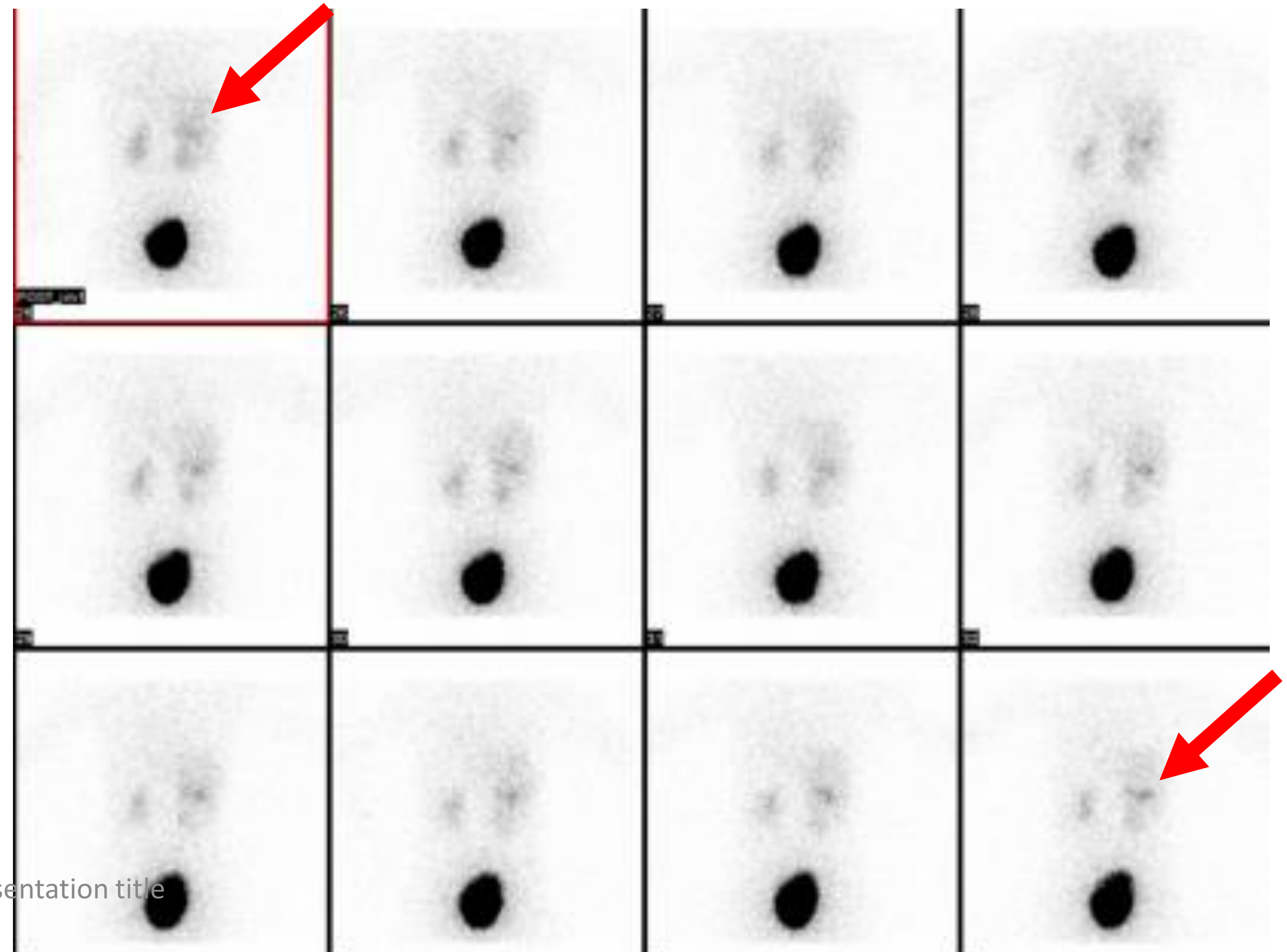
DRF: right 33%

-MAG3 may be taken up by the liver with subsequent excretion into bowel.

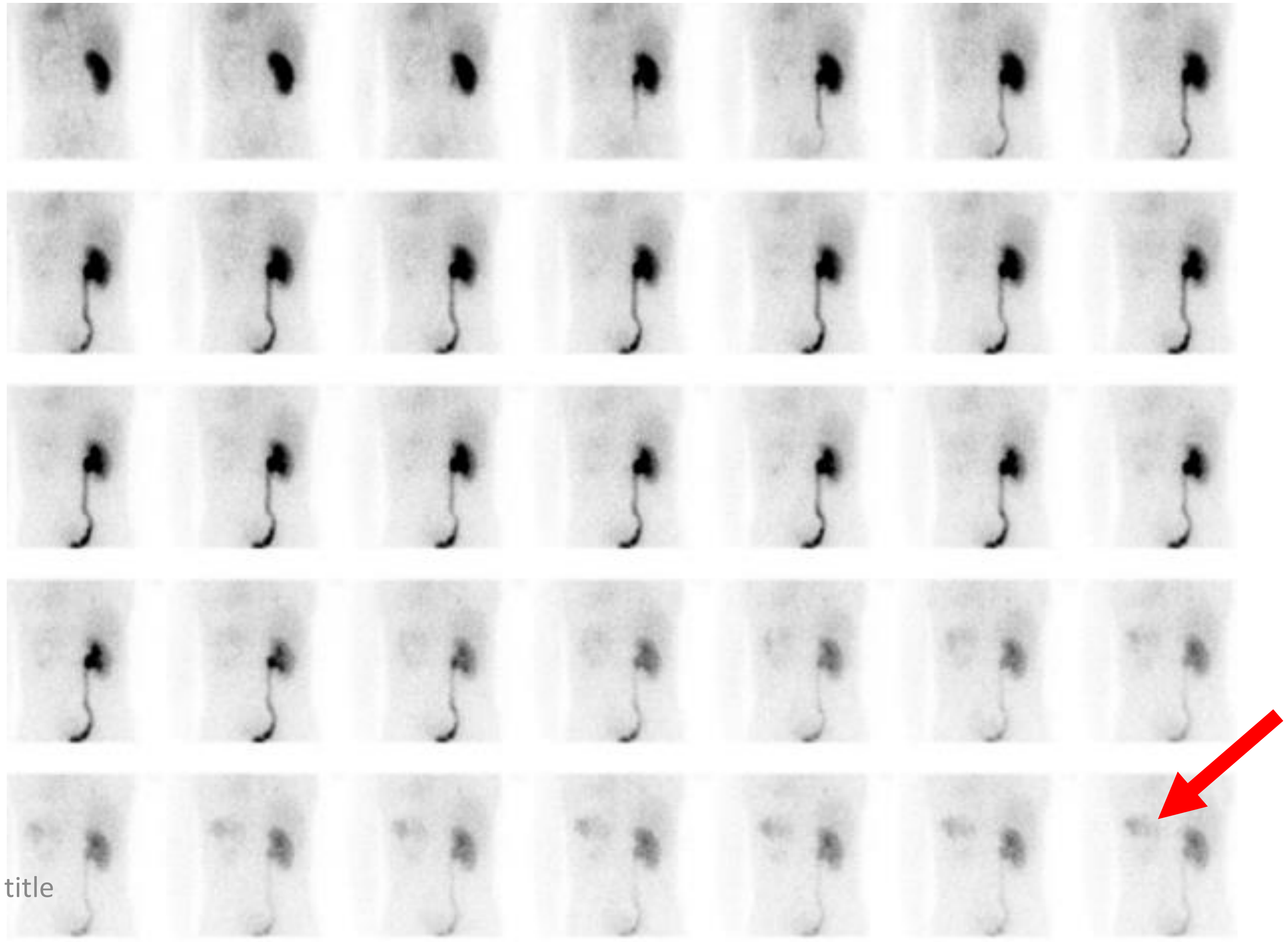


DRF: right 45%

Appearance of GB should not be mistaken with reflux in MAG3 scan (physiologic hepatobiliary excretion)



Appearance of stomach due to free Tc-99m, close to upper pole of left poorly functioning kidney- should not be mistaken with reflux



Dynamic Scintigraphy:

Perfusion and Function

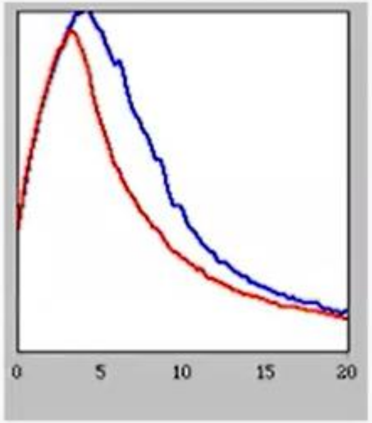
- Function: Cortical, Excretion, Drainage

Cortical Function➔ Qualitative + Differential Renal Function (DRF)

Drainage➔ Obstruction

Importantly: dilated unobstructed vs obstructed

Dynamic Renography (^{99m}Tc-MAG3)

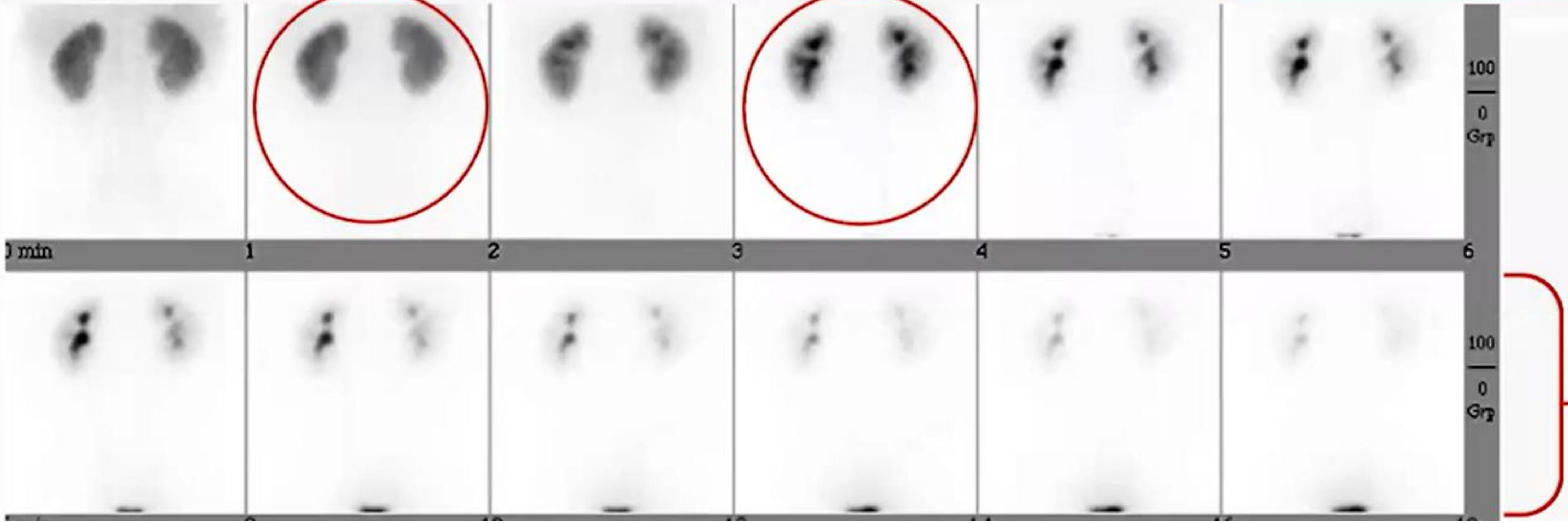


Cortical/Parenchymal Phase
-location, size, perfusion
-overall and differential function

60-120 sec

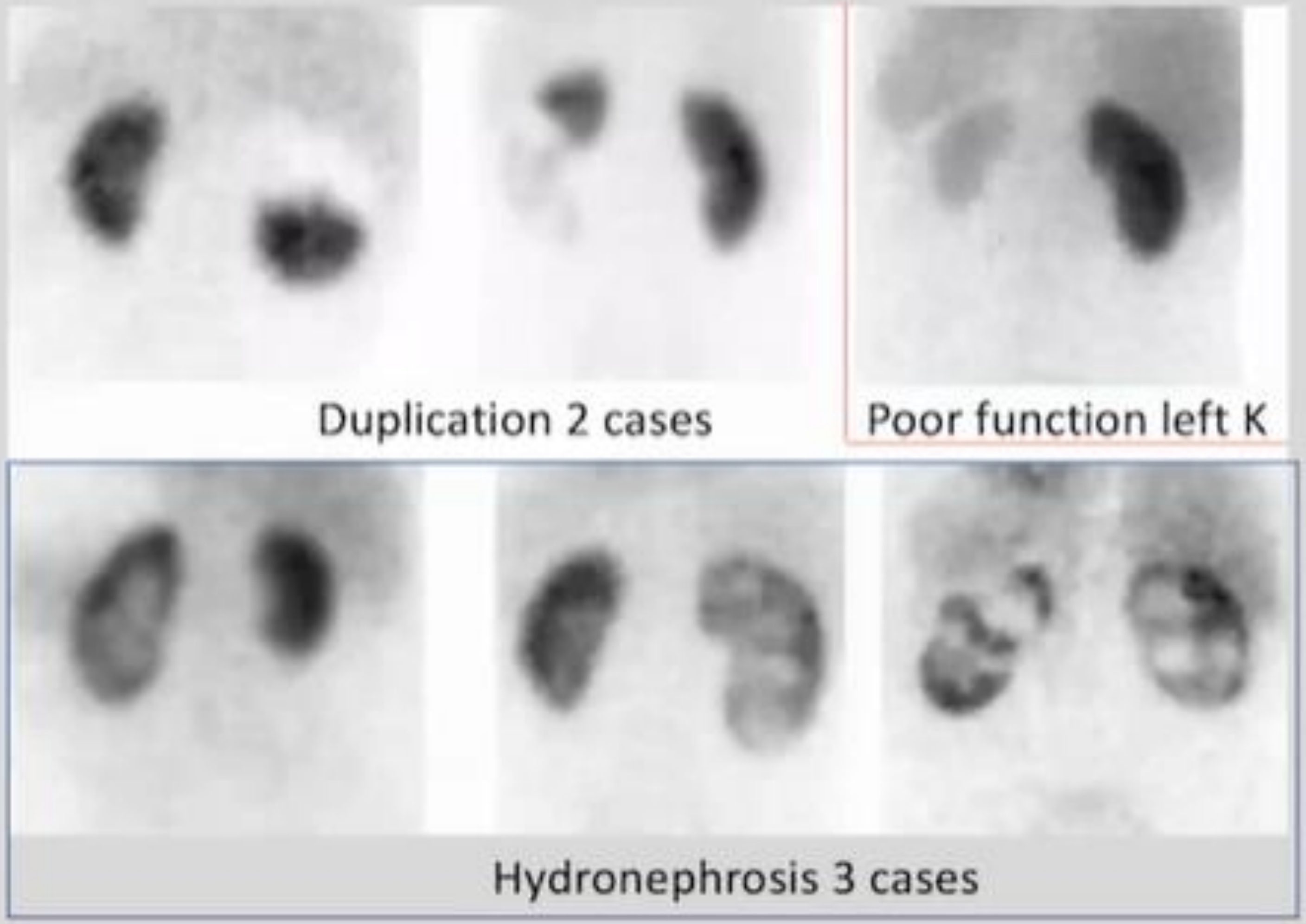
Transcortical transit
= cortical function
(normal: 2-6 min)

Drainage phase
-collecting system



Parenchymal phase (60-120 sec)
^{99m}Tc-MAG3

- Size
- Position
- Configuration
- Split and total function
- Defects

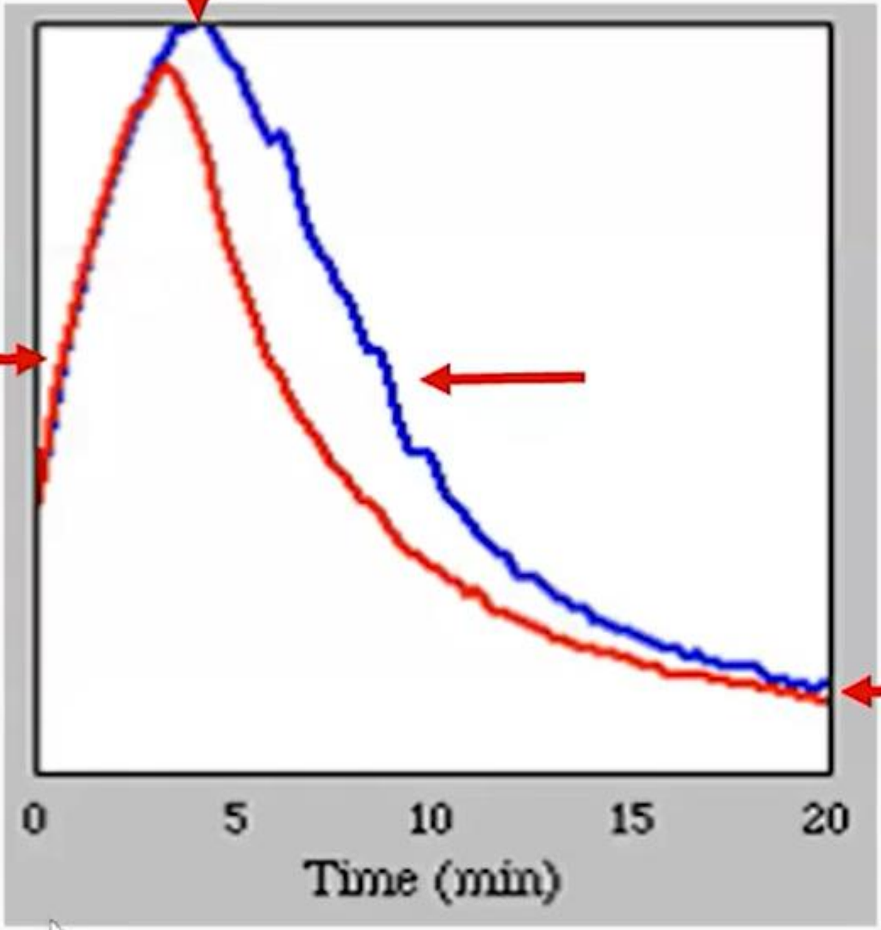


Always pay attention to the Mag3 Parenchymal phase!

Dynamic Renography: Time-Activity Curve

Peak < 7 minutes

Differential 50/50 ± 10%



Residual: <35% of peak

Residual Activtiy

< 35%

T1/2
Post- Diueretic Drainage

the time for the activity in the kidney to decrease to 50% of its maximum value

<10 min: **normal, no obstruction**

10-20 min: **Indeterminate / partial obstruction**

> 20 min: **obstruction**

Ultrasound

Ultrasound remains the primary modality for initial assessment.

Reporting should be in conjunction with US findings.

Dynamic Renal Scan **Tc-99m MAG3, Tc-99m EC**
Diuretic Renogram

Indications

- Hydronephrosis/Collecting system obstruction
  - dilated *vs.* obstruction
  - differential function
  - surgery *vs.* observation
- Transplant evaluation
  - Function, Drainage, Leaks

Neonates?

Renography ideally not to be performed in the first month of life.

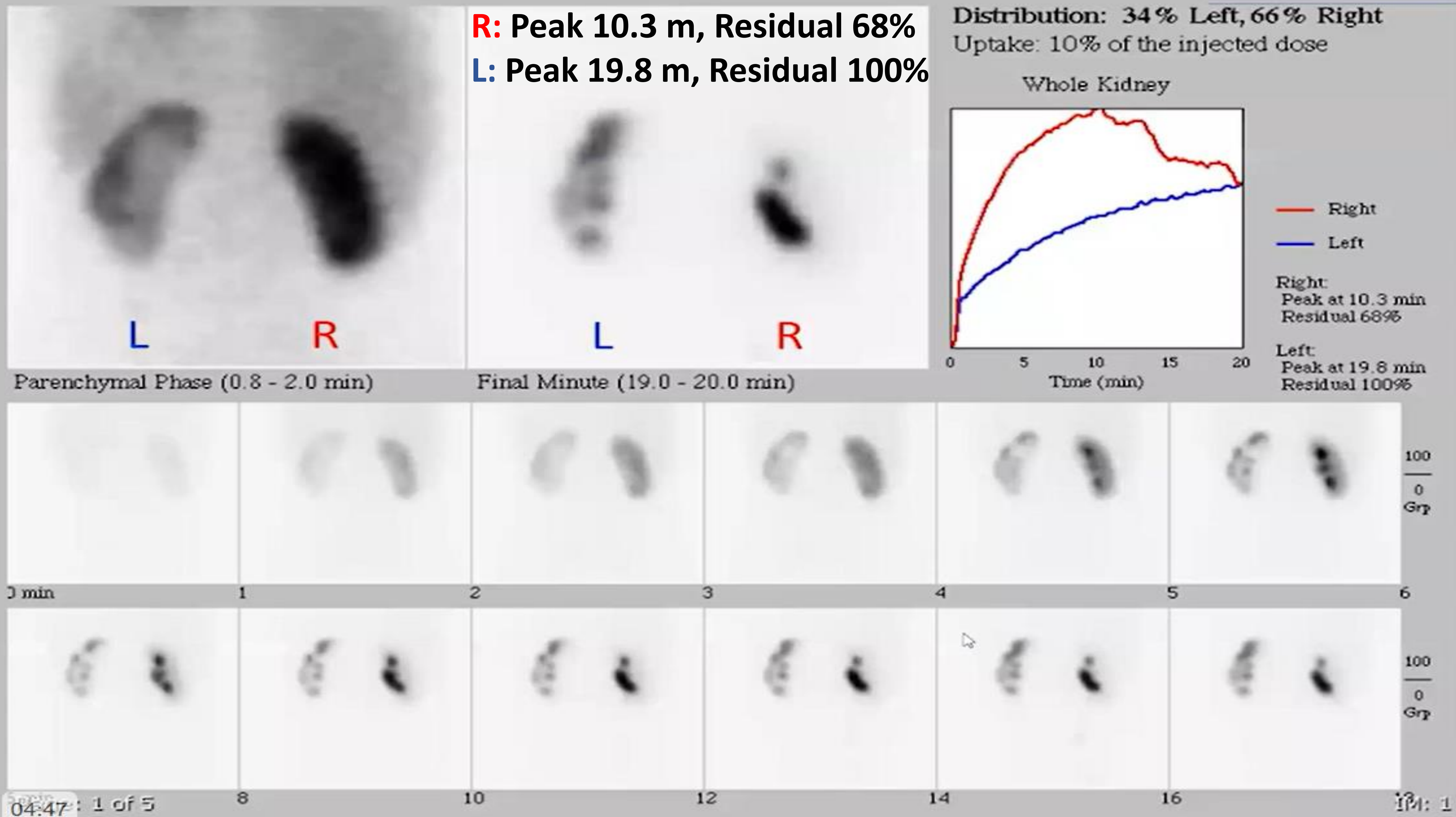
Timing: Typically performed at 6 weeks of age for infants.

Immature renal function (GFR about 30% adult): drainage assessment difficult.

(unless imminent surgery: needs a baseline)

Renal Immaturity and ^{99m}Tc-MAG3

- *Low renal uptake*
- *Prolonged transit time*
- *High background*


R: Peak 10.3 m, Residual 68%
L: Peak 19.8 m, Residual 100%
Distribution: 34% Left, 66% Right
Uptake: 10% of the injected dose
Whole Kidney
L
R
L
R
Parenchymal Phase (0.8 - 2.0 min)
Final Minute (19.0 - 20.0 min)
0
5
10
15
20
Time (min)
Right
Left
Right:
Peak at 10.3 min
Residual 68%
Left:
Peak at 19.8 min
Residual 100%
100
0
Grp
1
2
3
4
5
6
100
0
Grp
8
10
12
14
16
1 of 5
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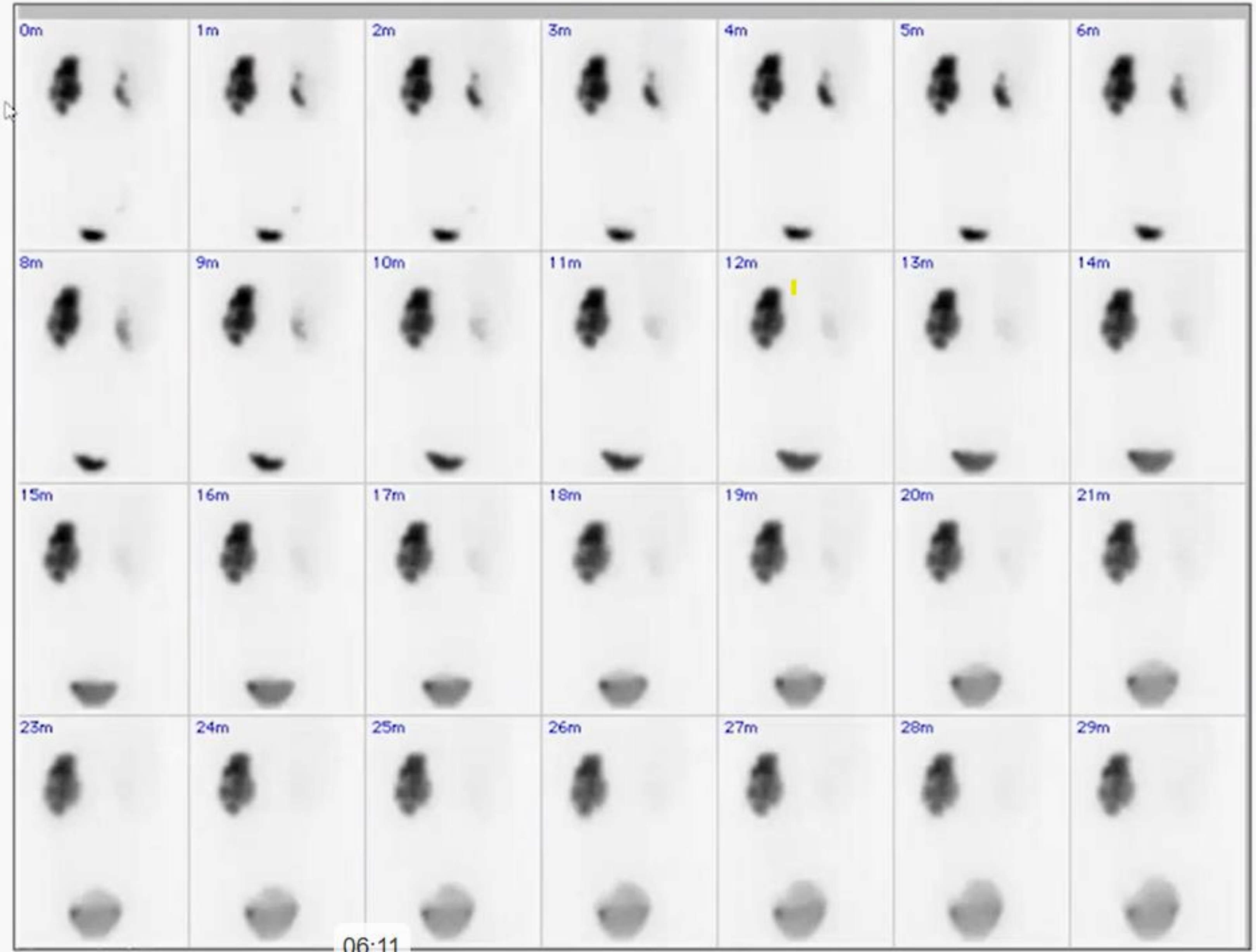
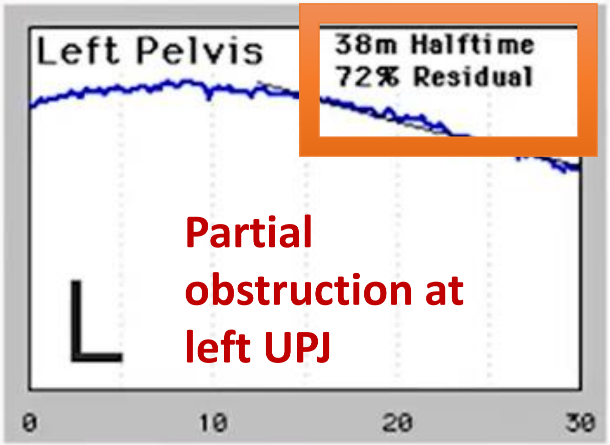
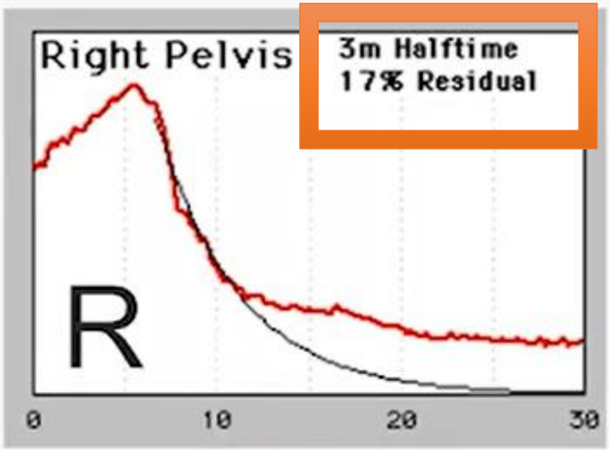
Diuretic Renogram (30 minutes)





Partial obstruction at left UPJ



Parameters:

Drainage halftime

30-minute residual

A point about pediatric UPJO and UVJO

Usually obstruction is **partial**

UPJO: intrinsic narrowing, extrinsic compression by a crossing vessel.

UVJO: narrowing of distal ureter, ectopic ureterocele, ectopic insertion of the ureter

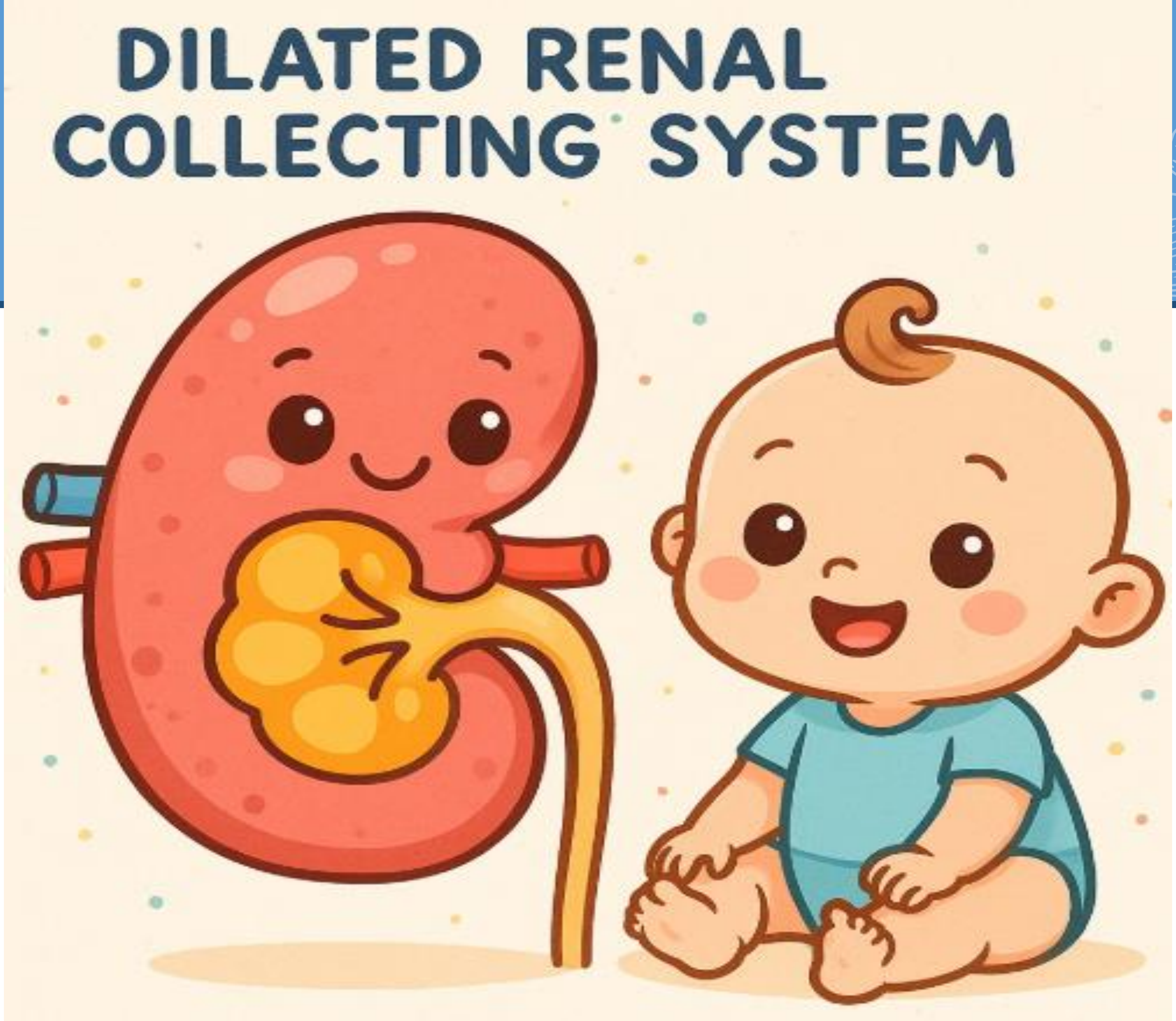
Complete obstruction of the proximal ureter during fetal development leads to **nonfunctional** kidney.

Diuretic Renogram: Three Approaches

- **F + 20 (U.S.)** **+30**
  - Dual-phase, defined diuresis parameters
- **F + 0 (Europe)**
  - Faster, all patients get lasix
- **F – 15 (Australia, U.S.)**
  - Can be disrupted by voiding

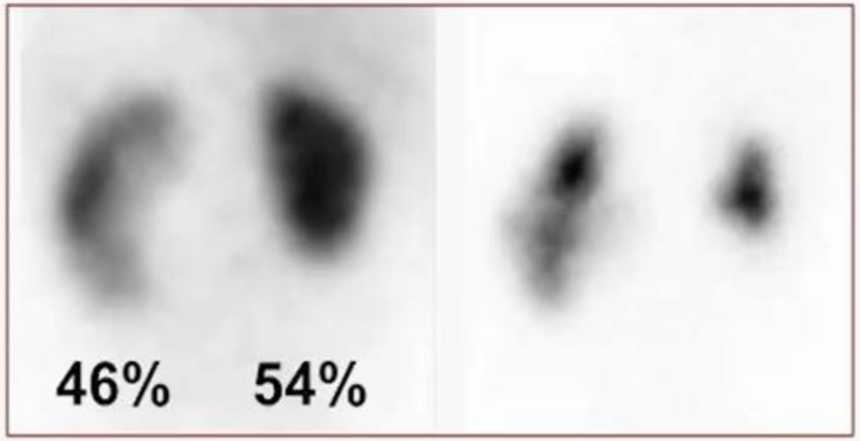
Which patients need bladder catheter?

- Not toilet trained
- Neurogenic bladder
- Dysfunctional bladder

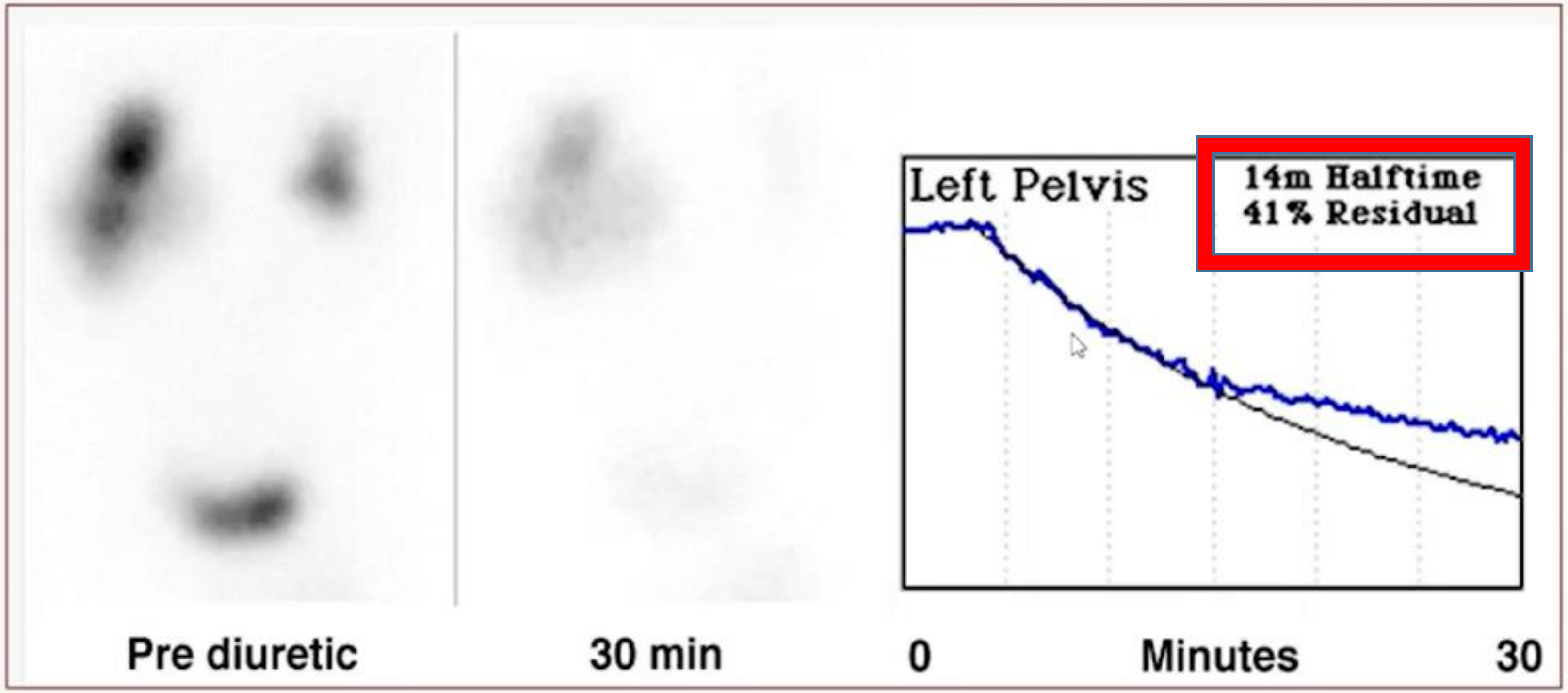

DILATED RENAL
COLLECTING SYSTEM

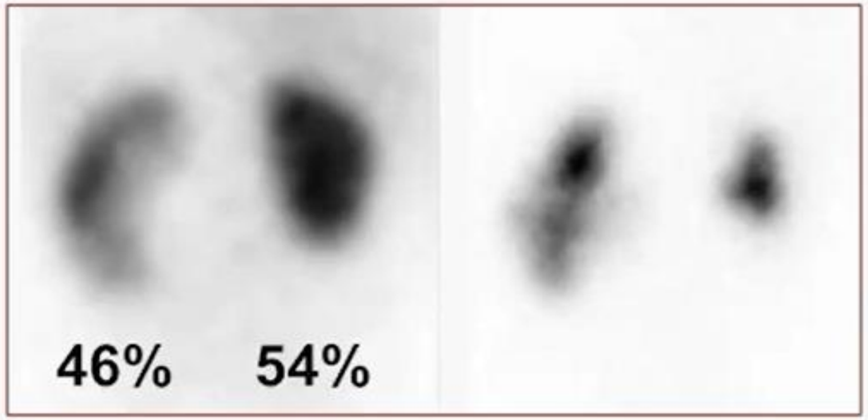
Postnatal Urinary Tract Dilation

- Ultrasound provides anatomic classification
  - Diagnosis
  - Risk assessment
- MAG3 renogram provides physiologic assessment:
  - Obstruction *vs* dilation
  - Improved risk assessment for renal injury
  - Guide need for intervention (surgery)
  - Post-surgical follow-up

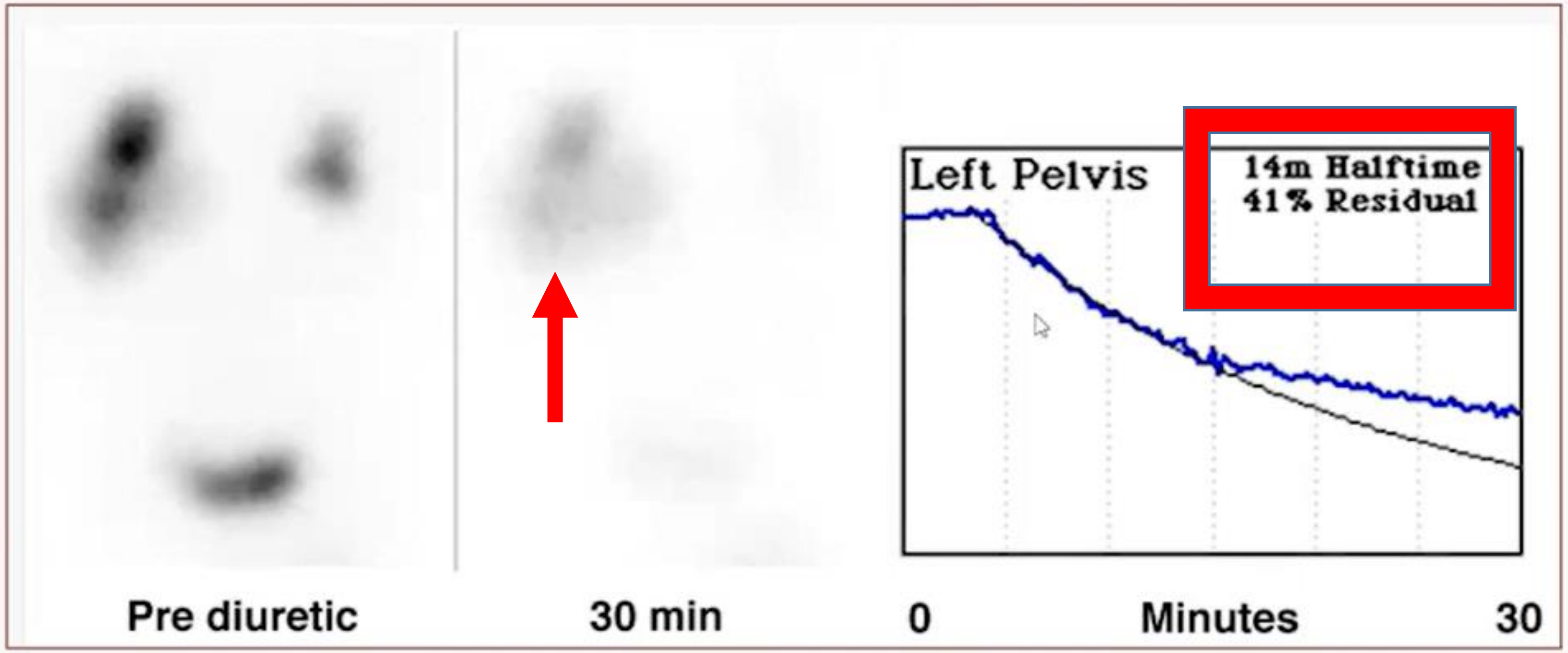


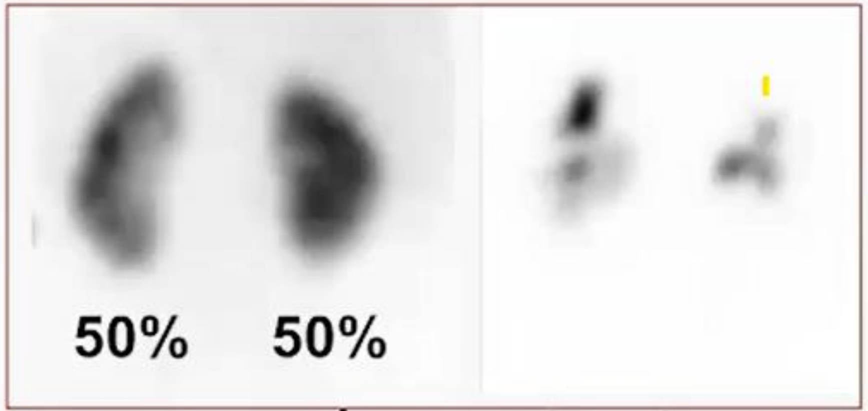
2 mo., Ultrasound: left hydronephrosis



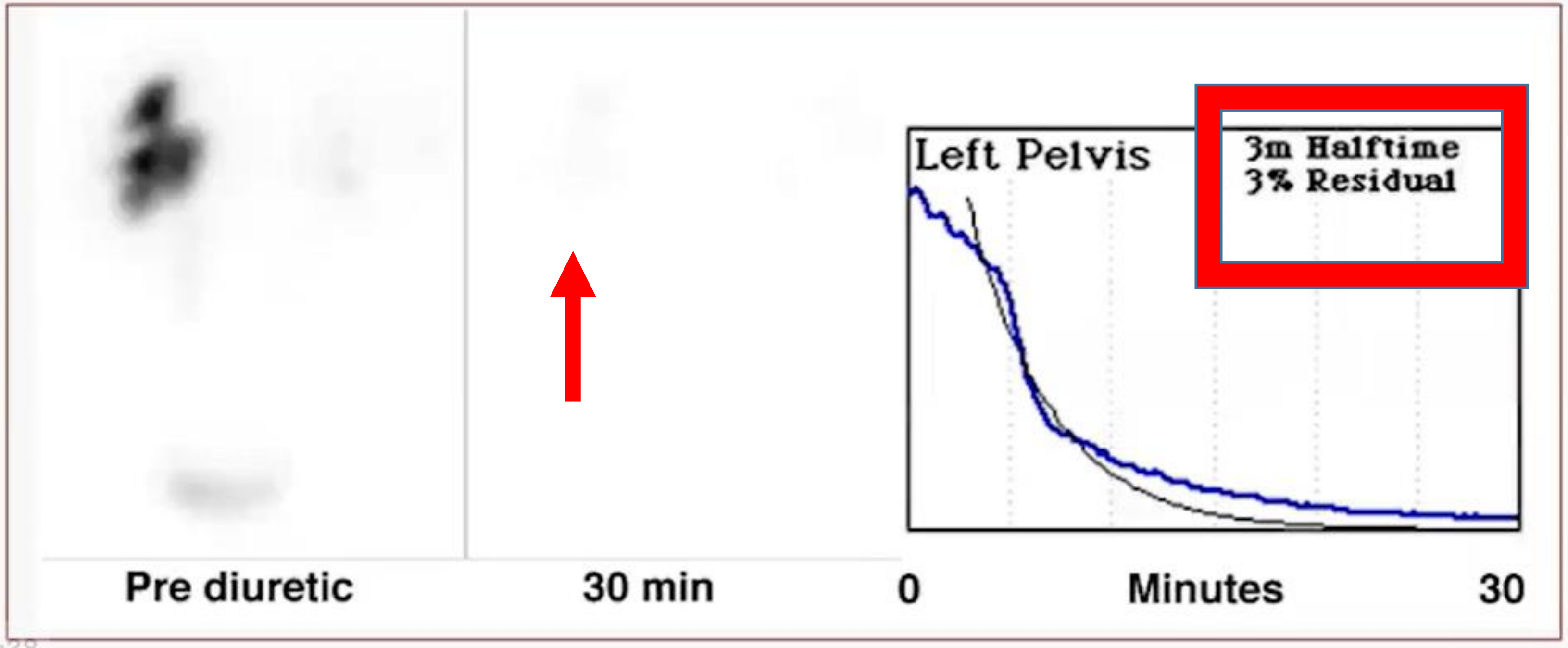


2 mo., Ultrasound:
left hydronephrosis





5 mo., s/p pyeloplasty, Ultrasound: stable left hydronephrosis



In post-operative evaluation for renal function:

Note that post-Diuresis images are valuable

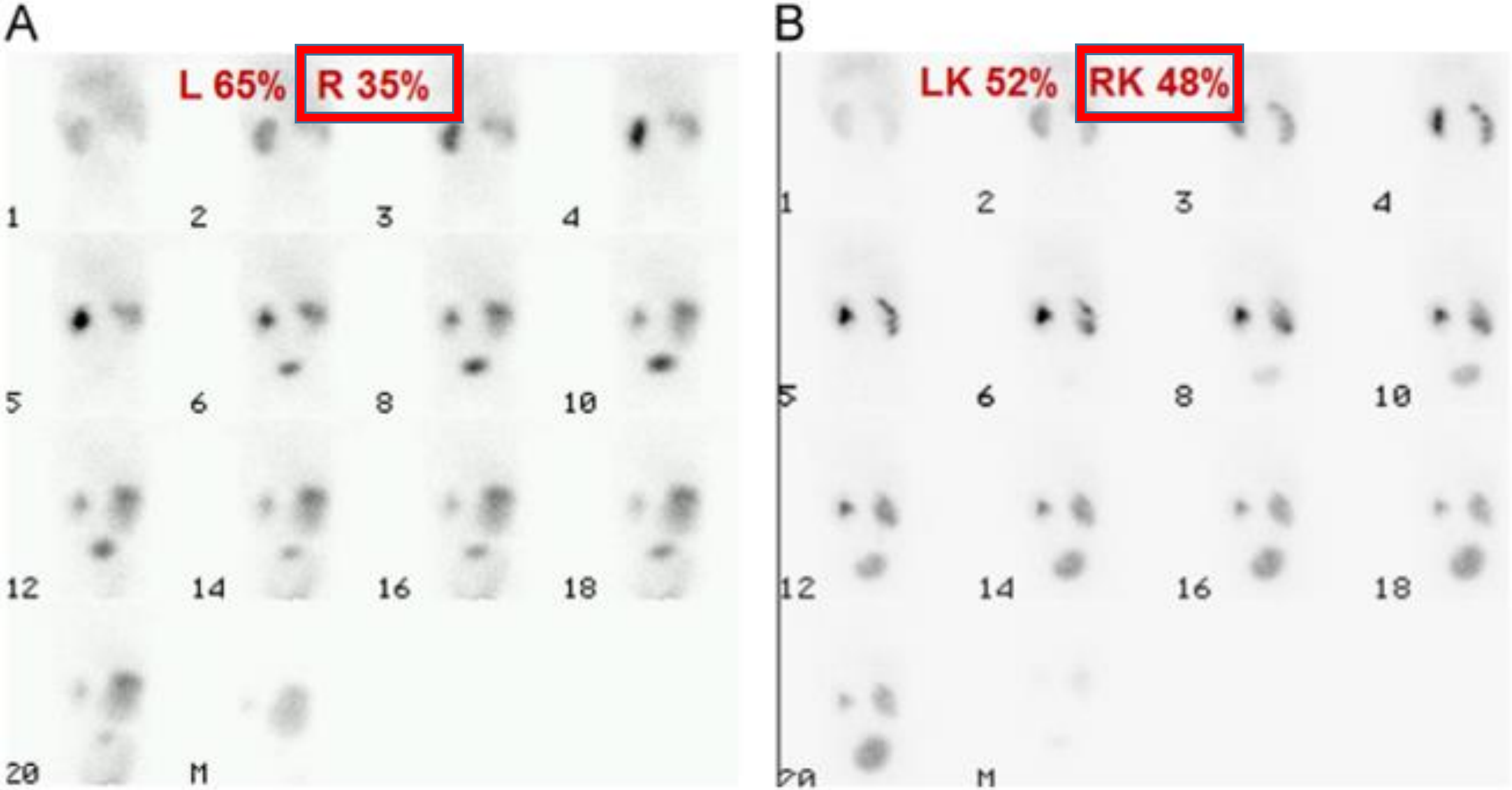
Normal:

T 1/2 < 10 min

Residual activity < 35%

For post-intervention compare T1/2+Residual activity +DRF

Antenatal Right HN diagnosis.
A- Base scan, B- 1 year after pyeloplasty



NORA

Dilation vs. Obstruction

NORA
Dilation vs. Obstruction

Reservoir- Effect:

Physically larger volumes take longer to clear than smaller volumes.

Analogy: Time to empty a small basin compared to a much larger bath.

Therefore: <u>normally</u> <u>longer time</u> to clear activity from the <u>hydronephrotic kidney than a normal kidney</u>.

Give a chance to dilated PC system to clear

NORA: Normalized Residual Activity

In children with hydronephrosis:

Most cases resolve naturally as part of physiological development.

So, when watchful waiting?

Clearance of activity after micturition and gravity assisted drainage (e.g., normal NORA):

Good predictor of

spontaneous improvement → therefore F/U instead of immediate invasive intervention

NORA: Normalized Residual Activity

NORA definition:

- The remaining activity in the kidney at time t (over a period of 1 min) expressed as the ratio between time t and time 1–2 min (activity time t /activity time 1-2 min)

- time t can be calculated at any point of the renogram:

- end of renogram
- end of furosemide test
- after micturition and gravity assisted drainage (upright position)

Normal Values for NORA

- Normal kidneys usually <1
- It is unlikely that NORA PM below 1.5 might correspond to an obstructive phenomenon.

NORA: 90th Percentile Values

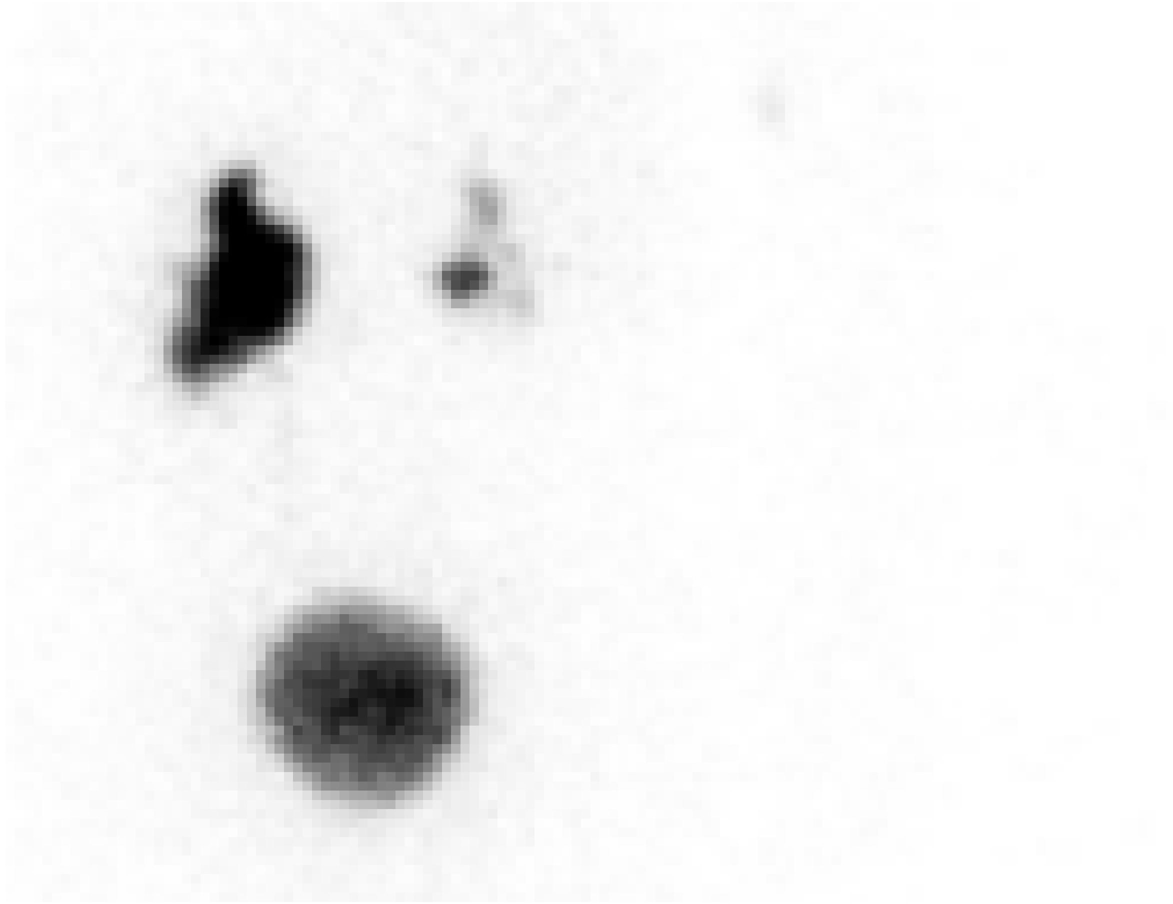
Kidneys	*n*	Timing for NORA	P90
Normal	175	20 min	0.70
	42	End of furosemide	0.23
	42	After micturition	0.10
Previous surgery	82	20 min	3.92
	75	End of furosemide	2.91
	65	After micturition	1.99

P90 = 90th percentile.

Piepsz et al. THE JOURNAL OF NUCLEAR MEDICINE • Vol. 43 • No. 1 • January 2002

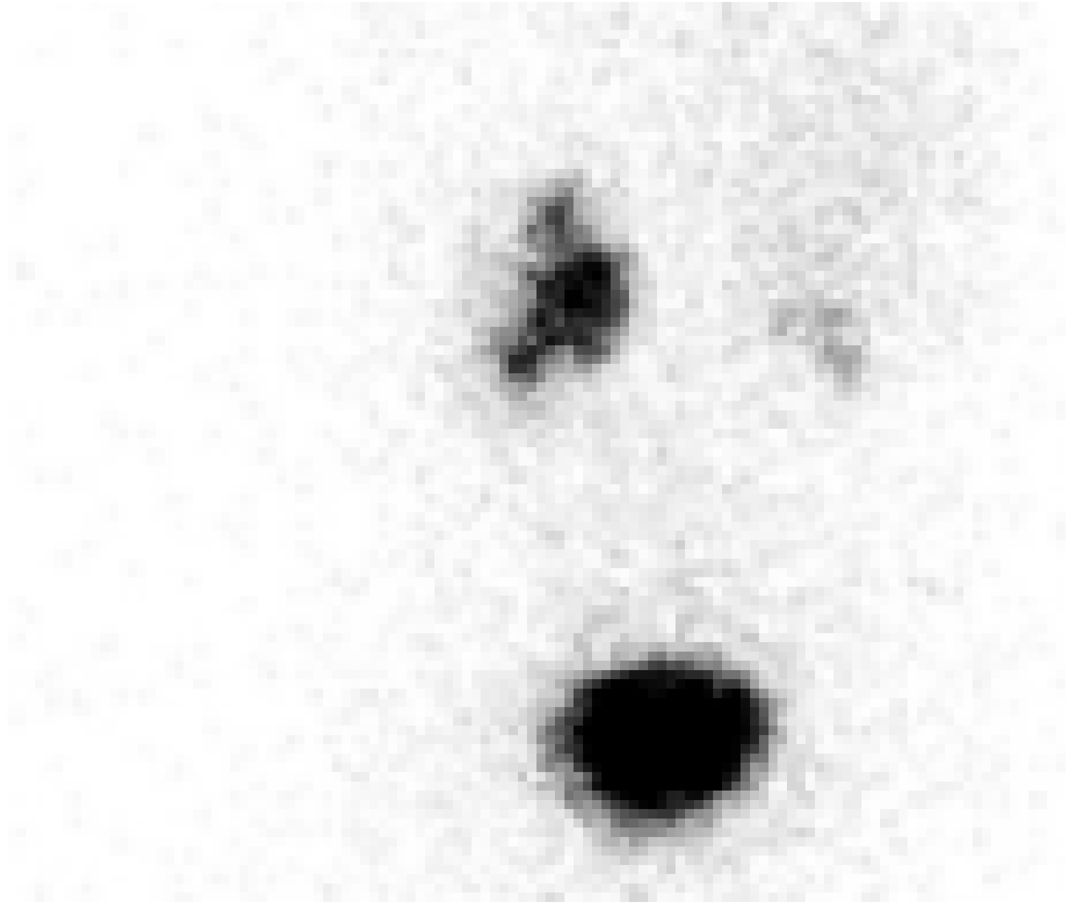
Dilated renal collecting system in pediatrics

post micturition and gravity assisted drainage image, visually there is still significant residual activity in the left kidney however, counts in the left kidney dropped to 4863 and the NORA to 0.33, excluding obstruction



total counts in the left renal ROI were 28,476,

NORA 2.04.



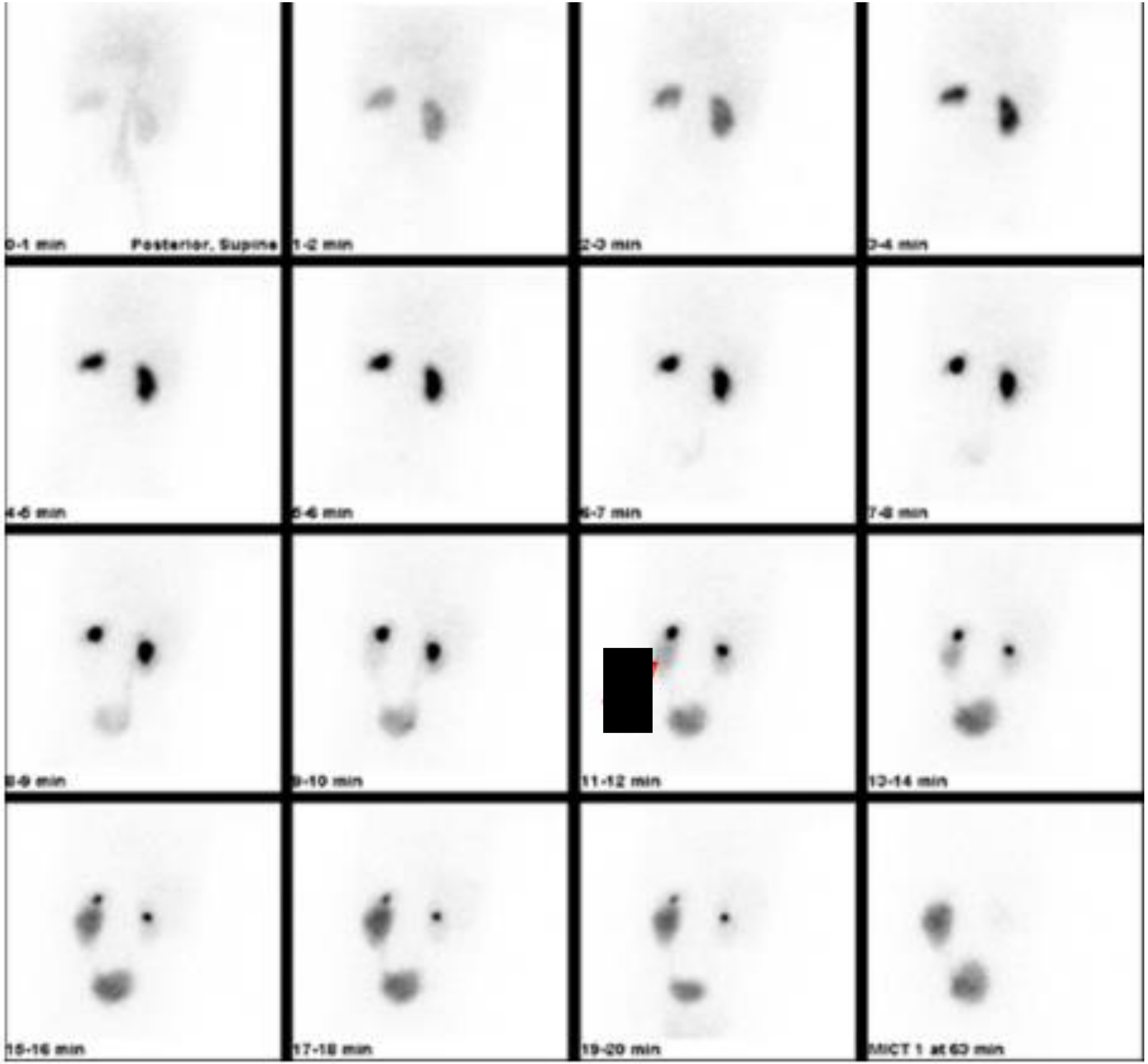
total counts in the left kidney dropped to 4863

NORA 0.33, excluding obstruction

Normal NORA :

- **A value of less than 1.0** at the end of the renogram can correspond to a good renal drainage.

- **<u>High</u> NORA values** :
- kidneys that had **successfully undergone surgery**,
- Indeed, most of these kidneys remain dilated despite successful surgery, and the poor renal emptying reflects only the stasis in these dilated cavities.


0-1 min
Posterior, Supine
1-2 min
2-3 min
3-4 min
4-5 min
5-6 min
6-7 min
7-8 min
8-9 min
9-10 min
[redacted]
11-12 min
13-14 min
15-16 min
17-18 min
19-20 min
MICT 1 at 63 min

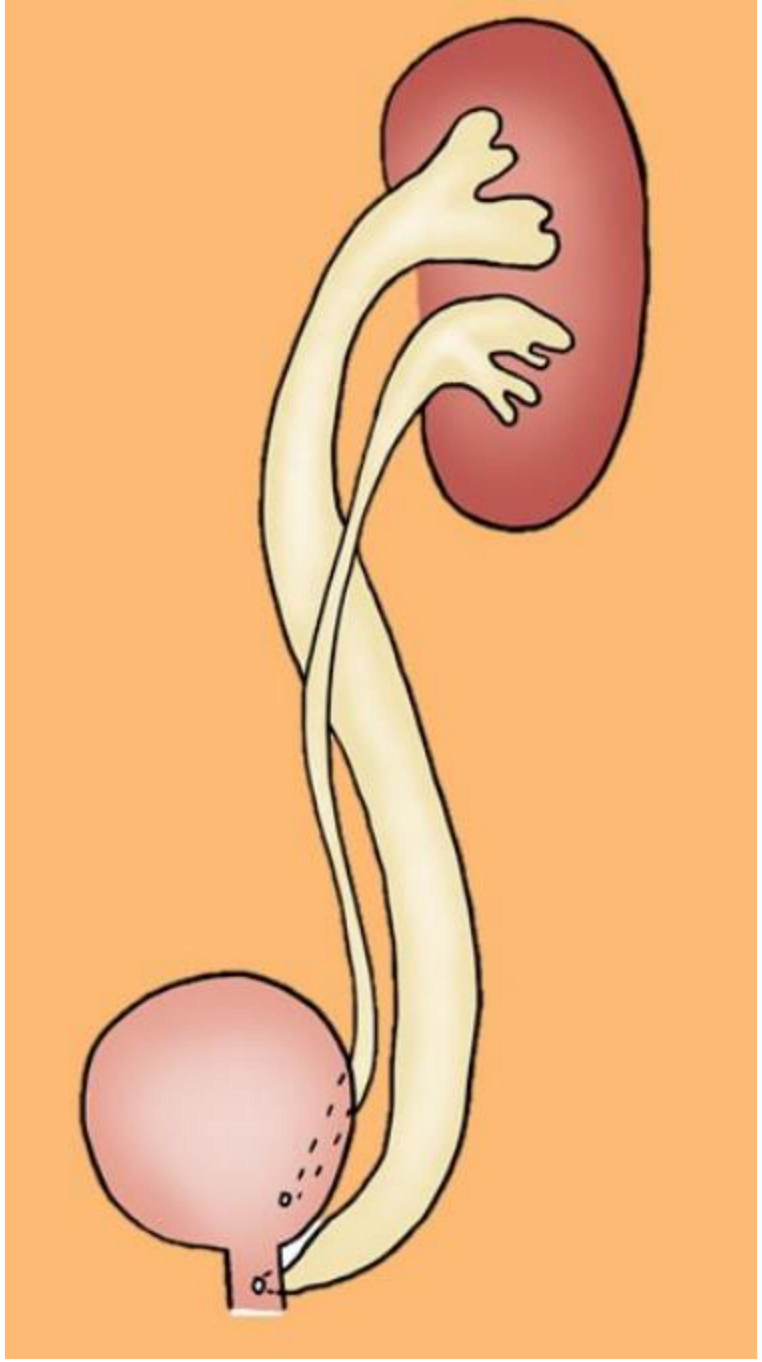
Weigert-Meyer law for Duplex Kidney:

- **Upper moiety ureter:**
- **- More prone to obstruction**

- Ectopically inserts medial and inferior to the ureter of lower pole moiety, frequently ends in a ureterocele.

- **Lower moiety ureter:**
- **- More prone to reflux**

- Orthotopic insertion lateral and superior to the ureter of upper pole.

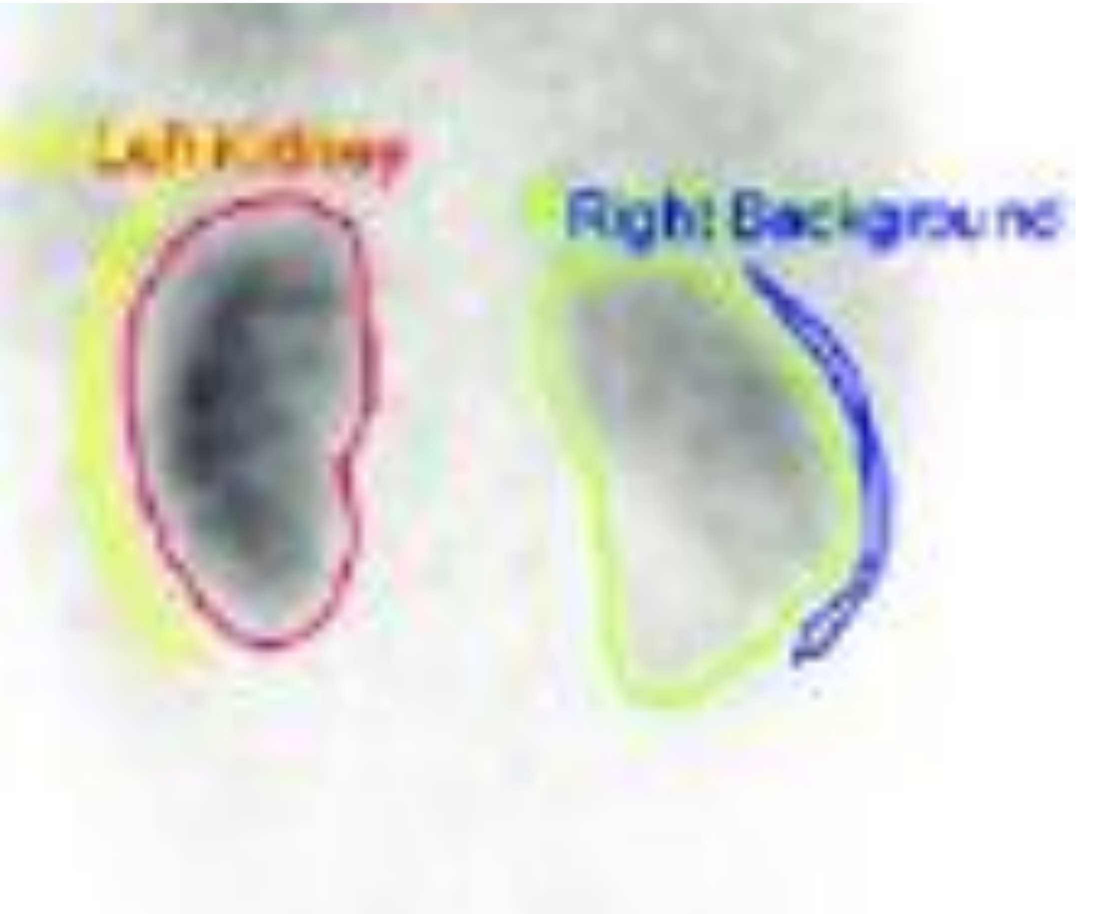


A reminding technical point on ROI selection:

ROI for DRF : Best the second image (60-120 sec)

Renal ROI should include only the entire functioning renal tissue

Preferred background ROI: Perirenal C-Shaped (semilunar) around and slightly separated from renal ROI



Infrarenal crescentic ROI overestimates percentage uptake by kidneys and differential function of hydronephrotic right kidney, while perirenal semilunar ROI aides in appropriate background subtraction and depicts realistic differential function

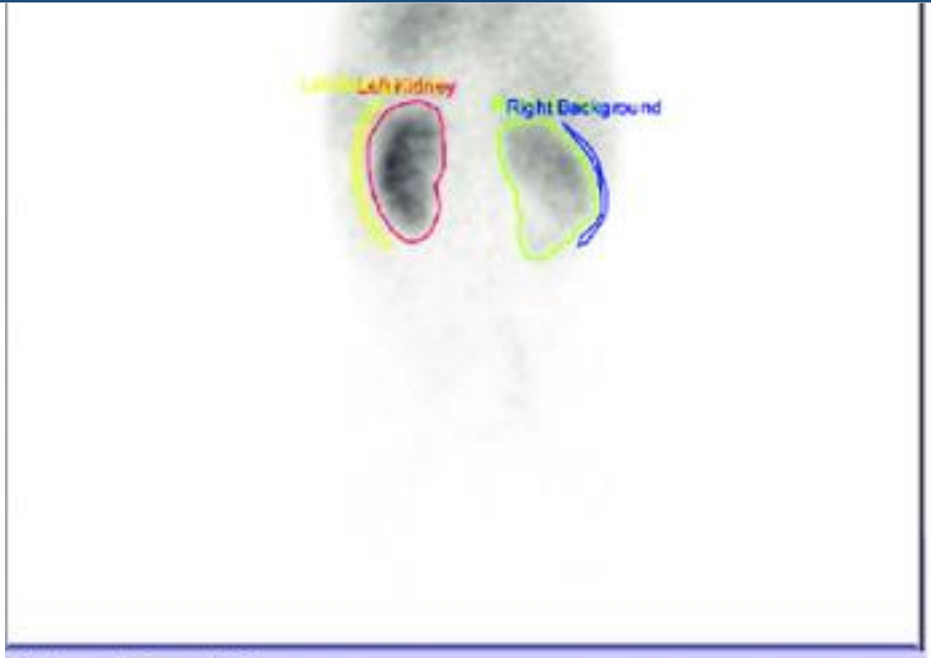


Table of Result Summary

Parameters	Left	Right	Total
Curve Fit	Off	Off	
Split Function (%)	62.5	37.5	
Kidney Counts (cpm)	28139	16910	45049
Kidney Depth (cm)	3.124	3.142	
Uptake (%)	3.899	2.343	6.242

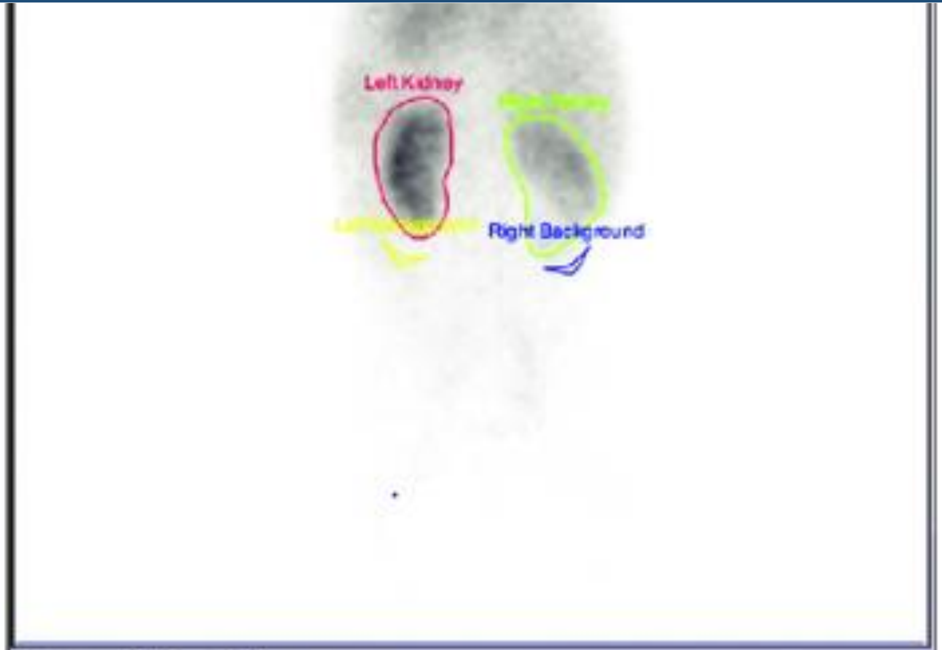


Table of Result Summary

Parameters	Left	Right	Total
Curve Fit	Off	Off	
Split Function (%)	57.2	42.8	
Kidney Counts (cpm)	35014	26197	61211
Kidney Depth (cm)	3.124	3.142	
Uptake (%)	4.852	3.630	8.482

ROI for post-diuresis TAC

- **Must include the entire dilated system:** **summed images to include the entire kidney and avoid missing renal activity.**
- **If the ureter is also dilated, it must be included in the ROI: Single ROI**
- **However, in small percentage of cases HUN, double or triple ROI is needed to exclude UPJ obstruction, from ureter:**

- **RIO upto the PCJ**
- **ROI on dilated ureter**
- **Total ROI**

Renal Cortical Scintigraphy

Tc-99m DMSA

Renal Cortical Scintigraphy

- Localize kidneys
- Differential renal function
- Functional cortical anatomy
  - multicystic dysplastic kidney
- Infection/Scarring - highly sensitive

Cortical uptake and retention of ^{99m}Tc-DMSA

Other applications of DMSA renal scan in pediatrics

- Congenital renal anomalies:
  - duplex kidneys
  - horseshoe kidneys
  - crossed-fused kidneys
  - multi-cystic dysplastic kidneys
- RVH: pre-and-post revascularization procedures (angioplasty or surgery)
- Complex renal calculi

Renal Cortical Scintigraphy (^{99m}Tc-DMSA)

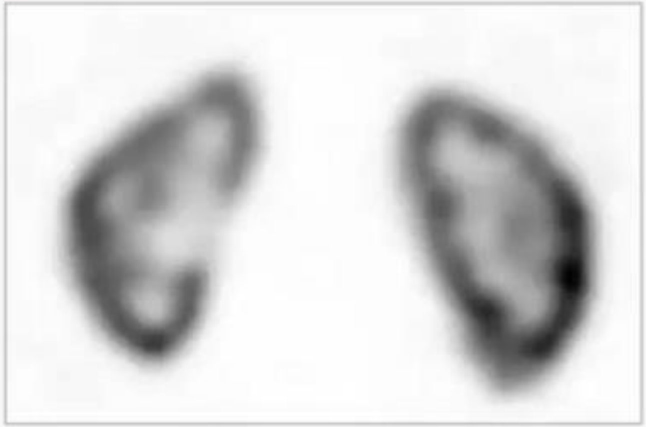
posterior

Planar

RPO

Pinhole

Especially in small infants



coronal

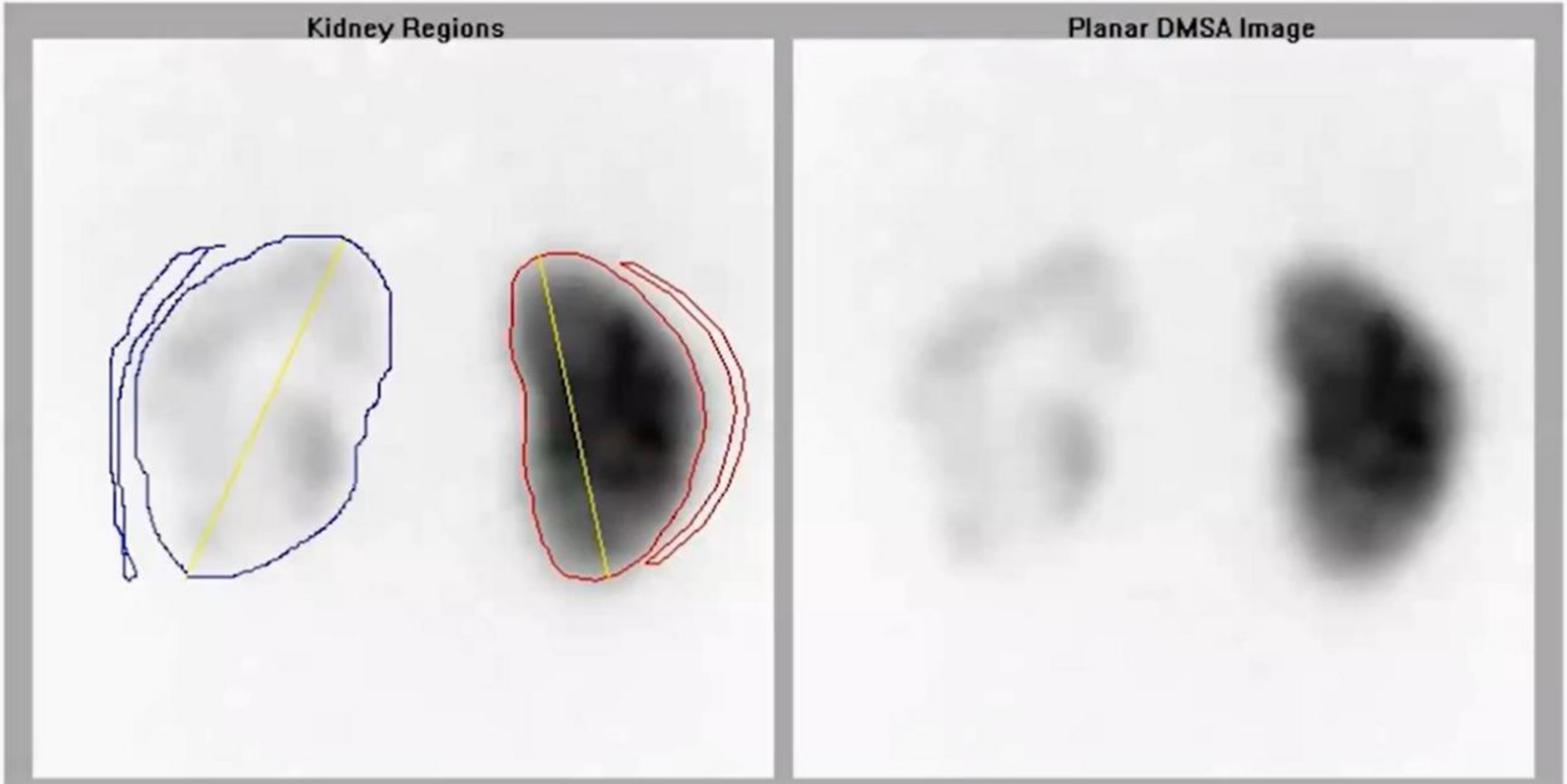
sagittal

axial

SPECT

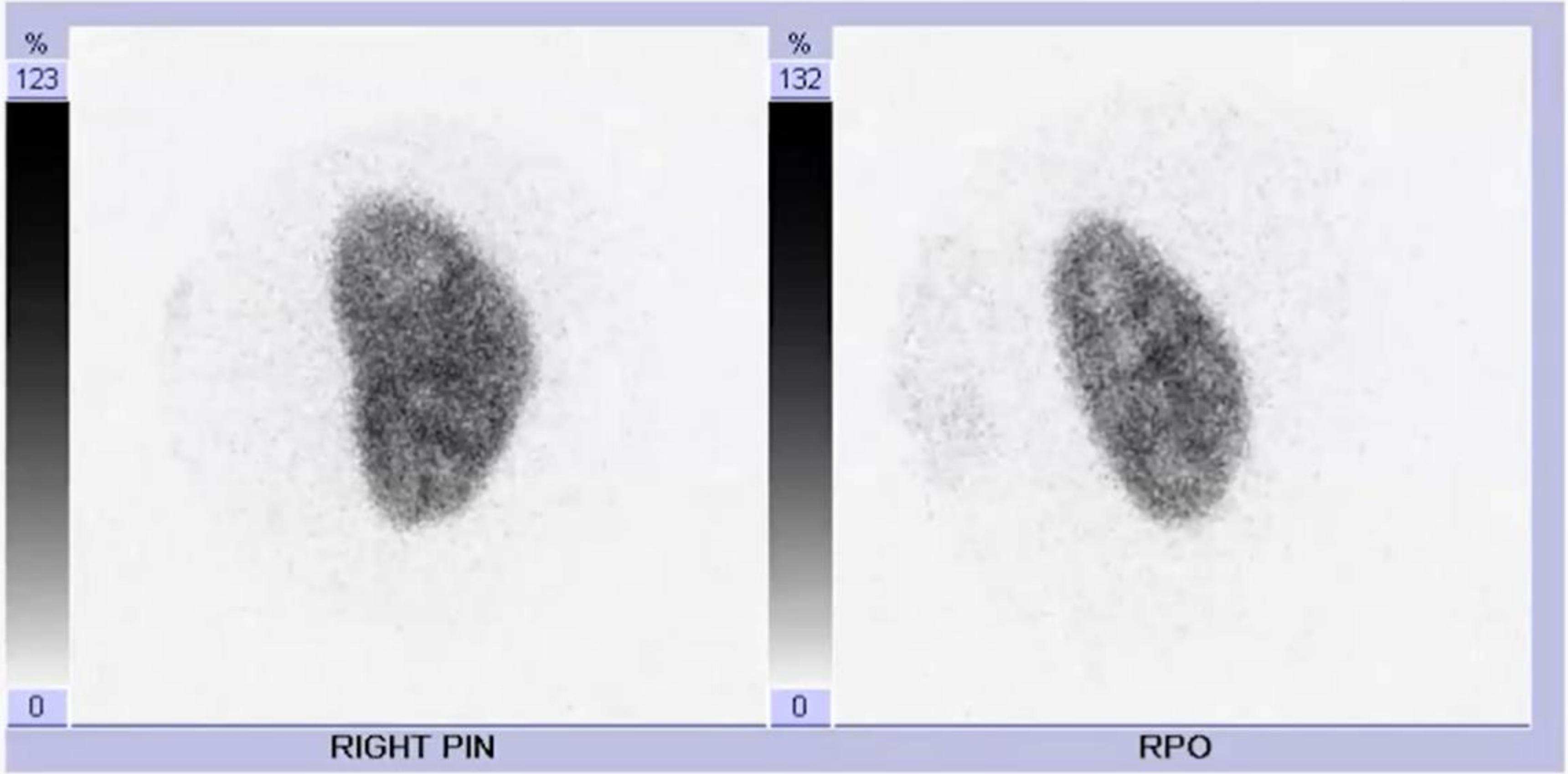
More than 1 year

5 month old boy with hydronephrosis and VUR

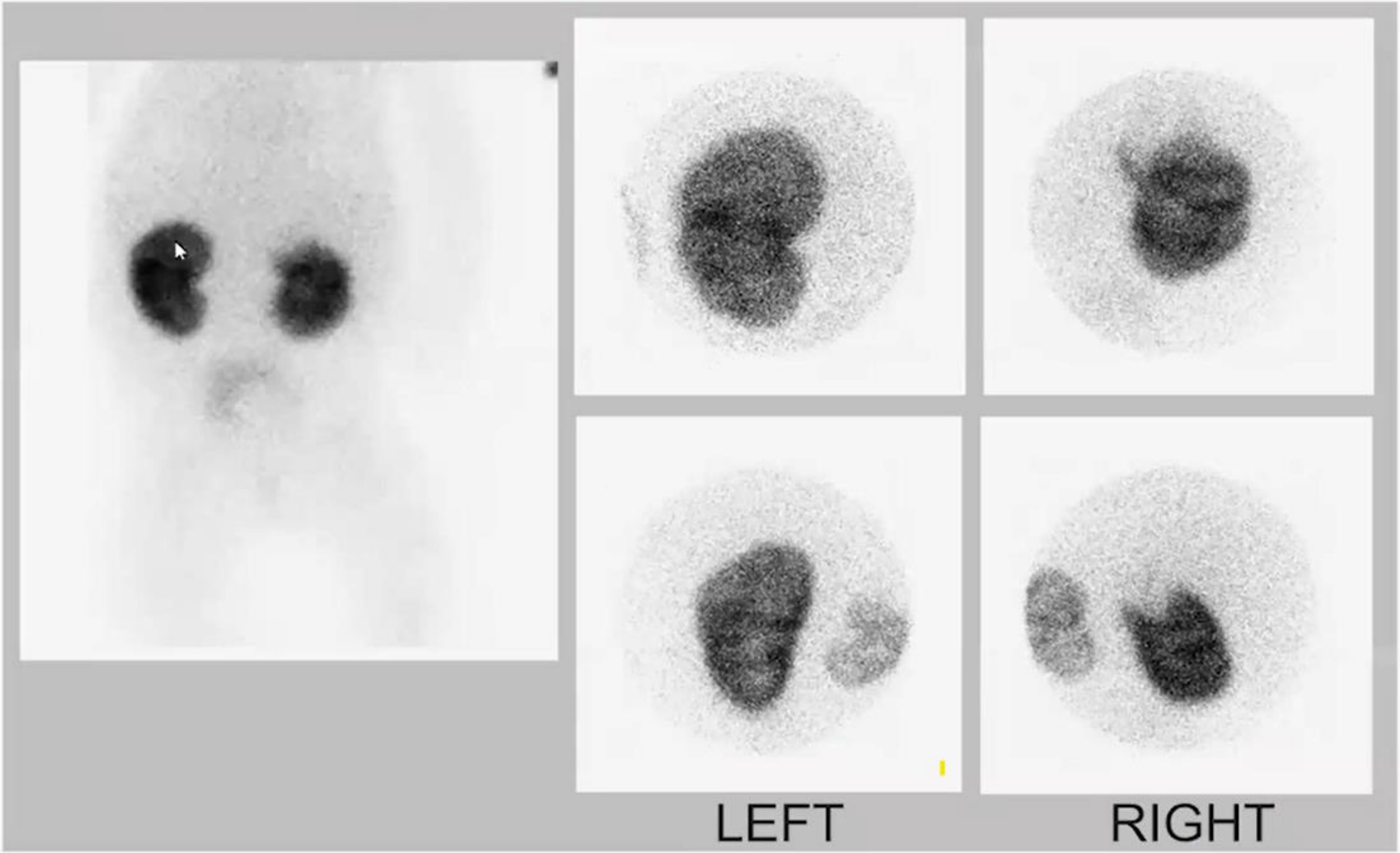


	LEFT	RIGHT
Ratio (%)	17	83
Length (cm)	7.1	6.3

Renal Cortical Scintigraphy: Pinhole Imaging



Renal Cortical Scintigraphy:
5 month-old girl with febrile UTI's

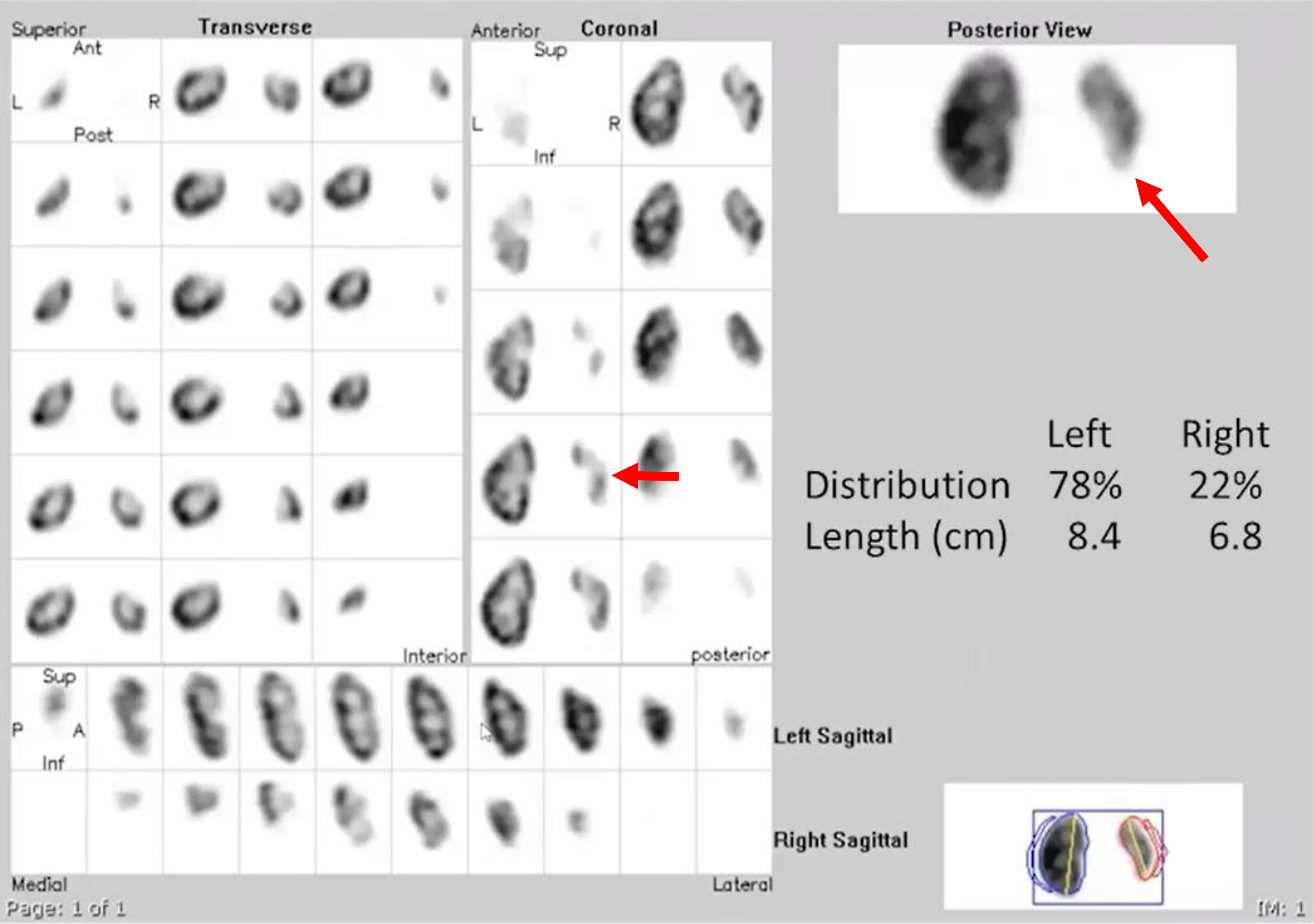


Renal Cortical Scintigraphy: Infection and Scarring

- Scintigraphy identifies focal defects with infection
- Focal defects may resolve or scar
- Clinical importance of renal cortical scarring
  - increased chance of young adult hypertension
  - risk of hypertension may increase over time
- Risk factor for renal parenchymal infection is vesicoureteric reflux (VUR)

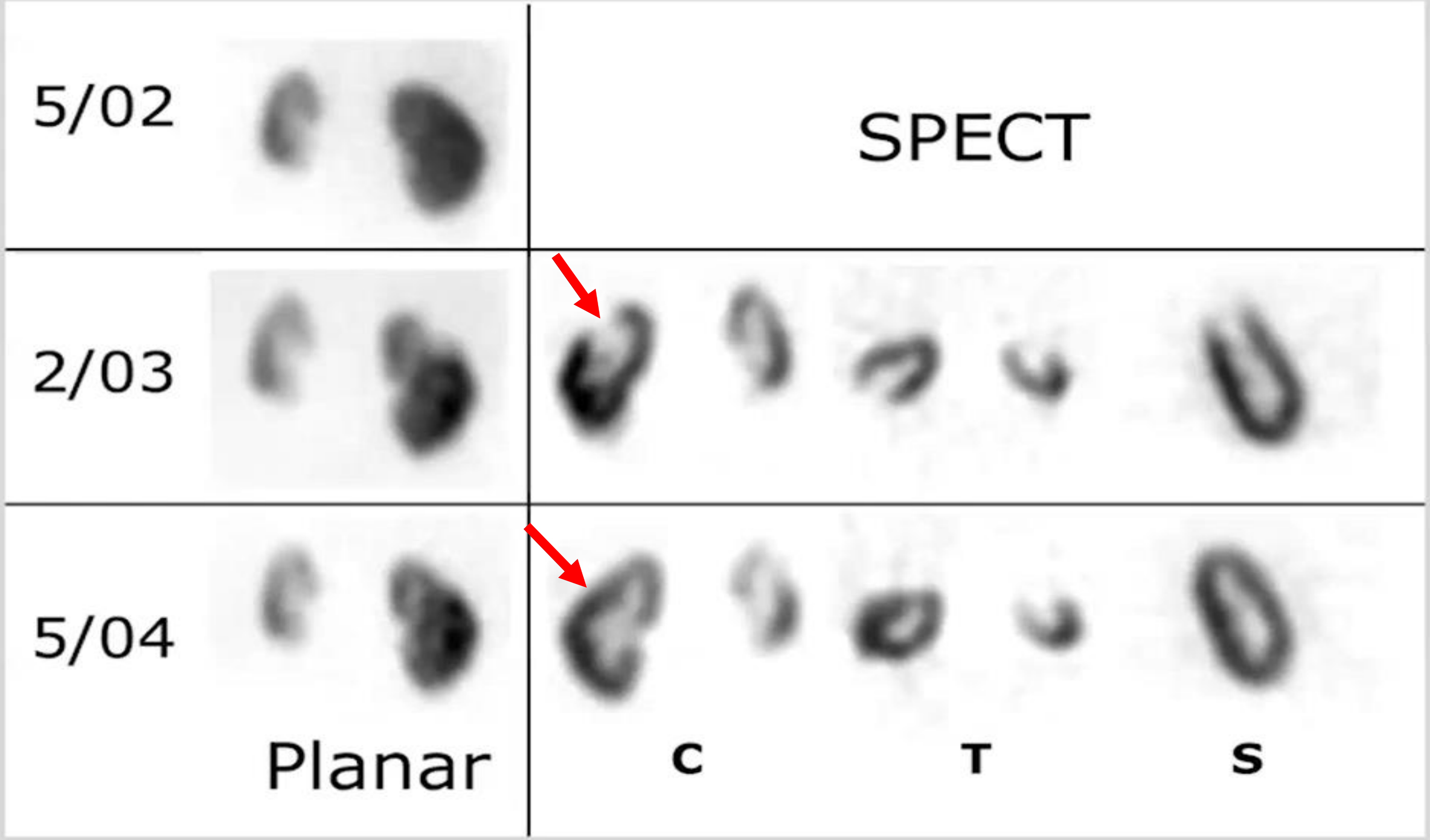
4 year-old boy with right vesicoureteral reflux

Extensive cortical scarring in the right kidney



	Left	Right
Distribution	78%	22%
Length (cm)	8.4	6.8

Comparison of planar images and SPECT: Recovery of cortical defects after pyelonephritis



“Acute” DMSA Scintigraphy:

- Performed during acute UTI phase.
- Reflects tubular dysfunction and ischemia.
- High sensitivity (>90%) for diagnosing acute pyelonephritis.
- Normal results: No renal scarring risk.

Acute PN DMSA vs. late scan

Significance of Late DMSA Scan

- Acute pyelonephritis may completely resolve, with scintigraphic images normalizing in **4-6 months.**

Inadequate or Delayed Antibiotic Treatment➔

Scar vs. Acute PN

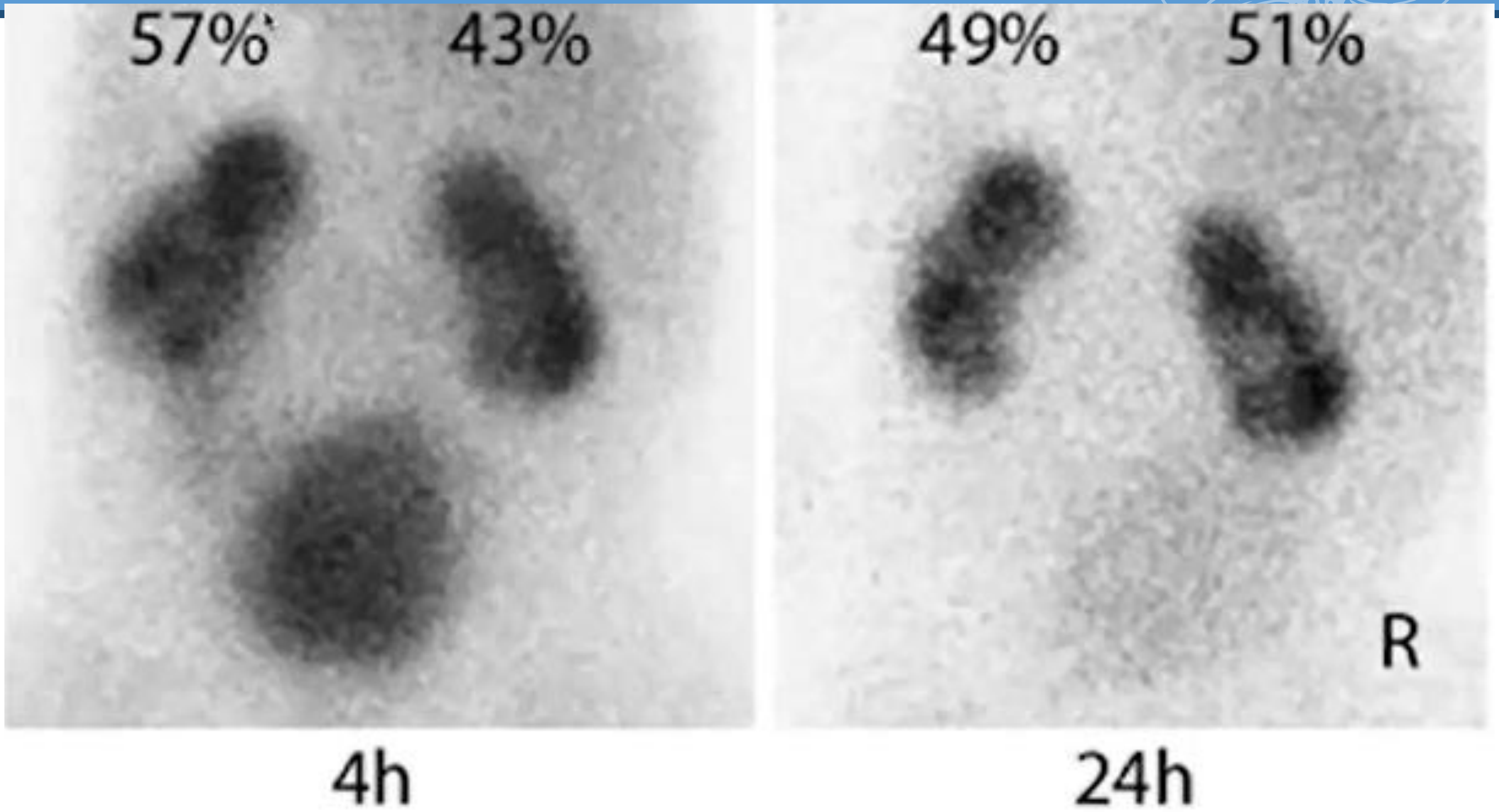
Scars:

- Cortical thinning/ Volume loss
- Flattened renal contour
- Wedge-shaped or more well-define defects

Acute PN:

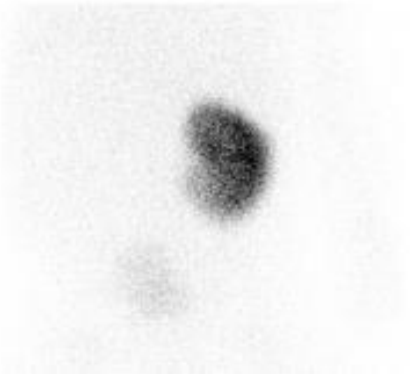
- Less sharp defects
- Diffuse decreased uptake
- Patchy reduced uptake
- May appear enlarged due to inflammation

At 4 hours after injection, some retention of tracer can occur in immature kidneys with hydronephrosis. Allowing the urine to drain and imaging several hours later provides
a more reliable assessment of split renal function

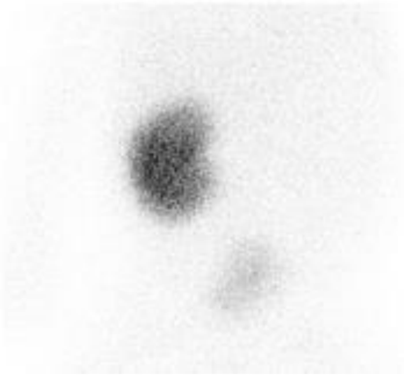


The small amount of [99mTc]Tc-DMSA excreted can frequently be seen in the bladder. Bladder activity may be mistaken for a pelvic kidney in the setting of renal agenesis.

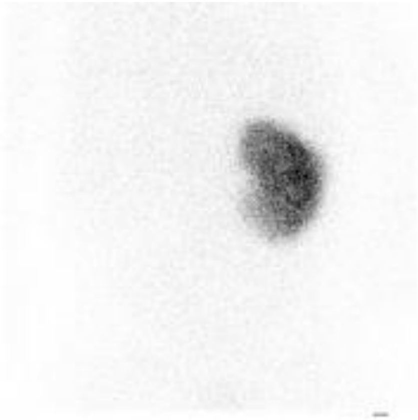
Posterior



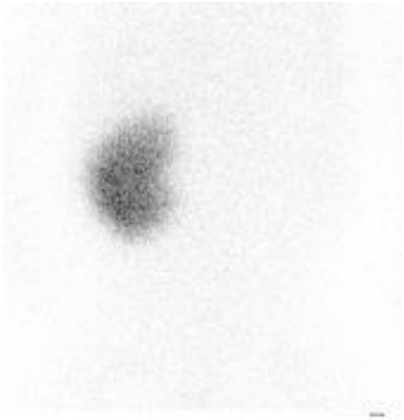
Anterior



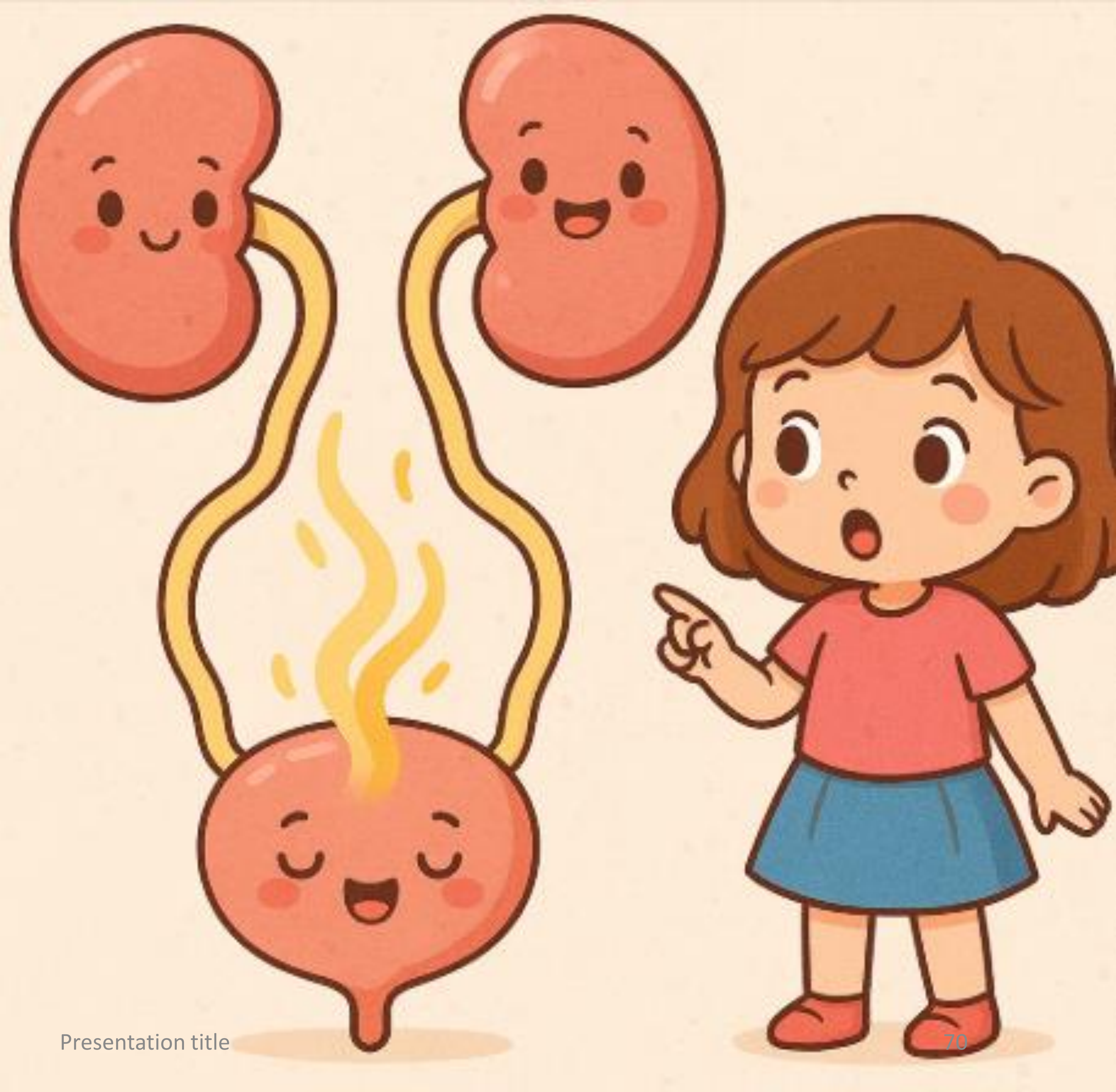
Posterior



Anterior



VESICOURETERAL REFLUX (VUR)



Vesicoureteral Reflux (VUR) Overview

- **Definition:**

VUR is the retrograde flow of urine from the bladder into the ureter and often into the renal collecting system.

- **Causes**

Congenital anomaly of the vesicoureteric junction (VUJ).

Secondary causes: High-pressure voiding due to posterior urethral valves, neuropathic bladder, or voiding dysfunction.

Clinical Importance:

- **Associated with pyelonephritis and reflux-related renal scarring.**
- **A common pediatric urological anomaly (~1% incidence).**
- **Higher incidence in children with UTIs (30%-50%, age-dependent)**

Ultrasound

First-line investigation for detecting reflux signs and scarring.

Spontaneous Resolution of VUR:

- Spontaneous resolution of VUR in low-grade reflux

(grades I and II: 80%, grades III-V: 30%-50% after 4-5 years).

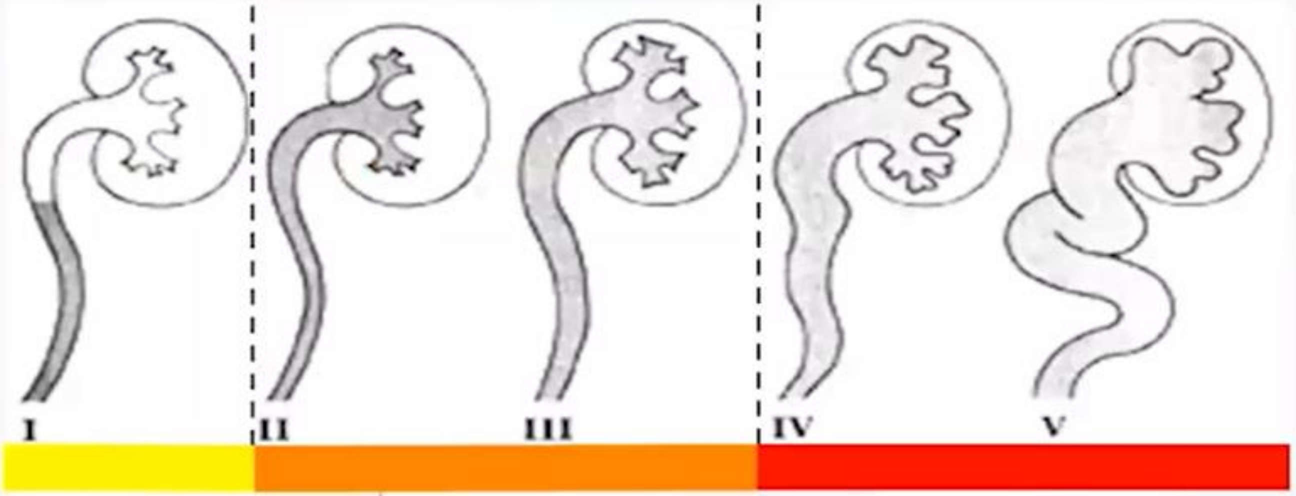
Depends on:

- Age, sex, grade, laterality, clinical presentation, and renal anatomy.

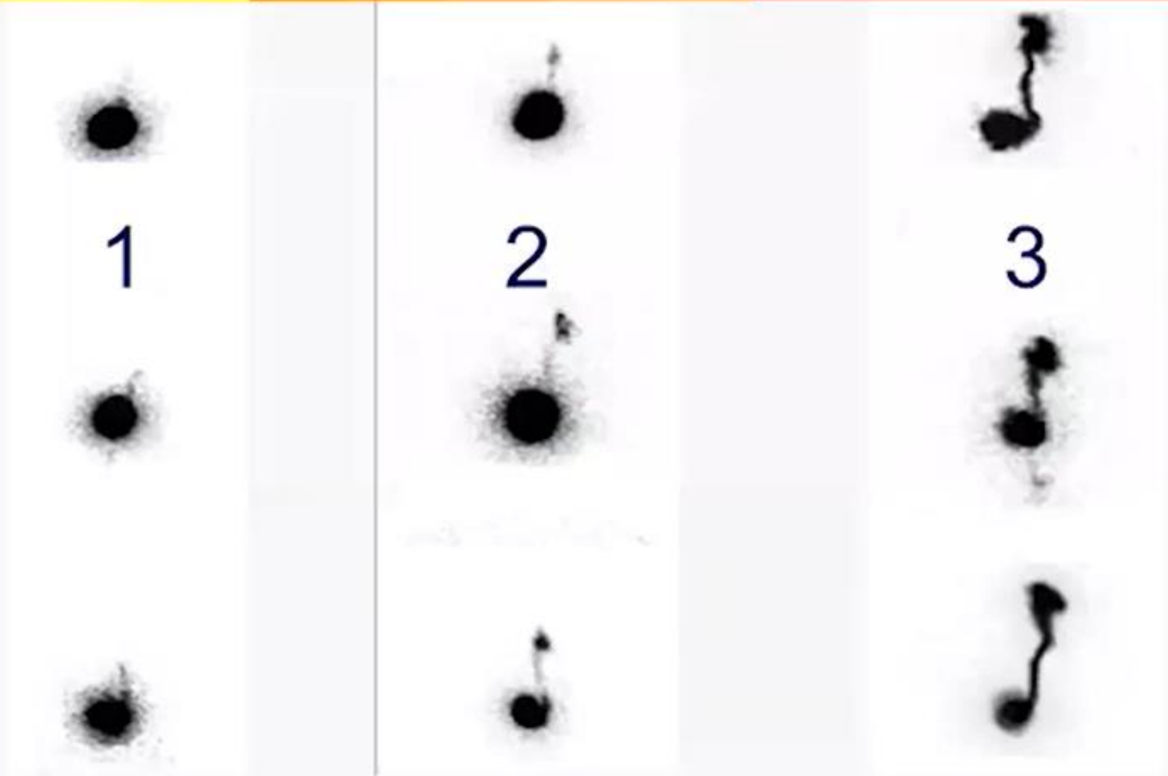
- No evidence that small scars cause significant kidney damage.

Grading Vesicoureteral Reflux

VCUG



RNC



VUR

- **<u>Radiographic</u> VCUG: Micturating Cystogram (MCUG): Gold Standard**

- Initial Diagnosis

- All children after the first febrile UTI

-Essential for infant boys to exclude posterior urethral valves.

VUR

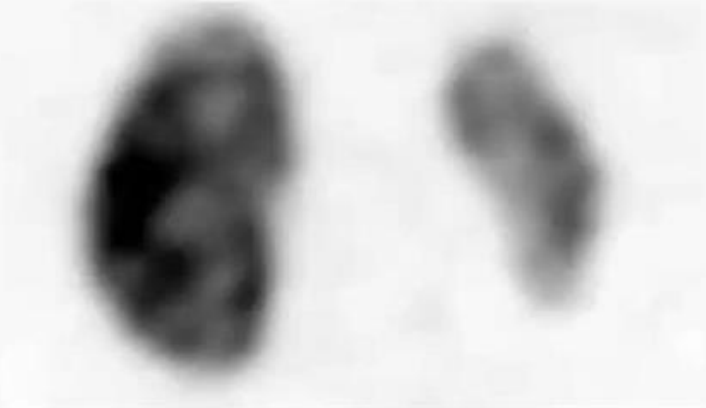
- **<u>RN</u> VCUG**
- **Direct Radionuclide Cystogram (DRC)**
- **Indirect Radionuclide Cystogram (IRC)**

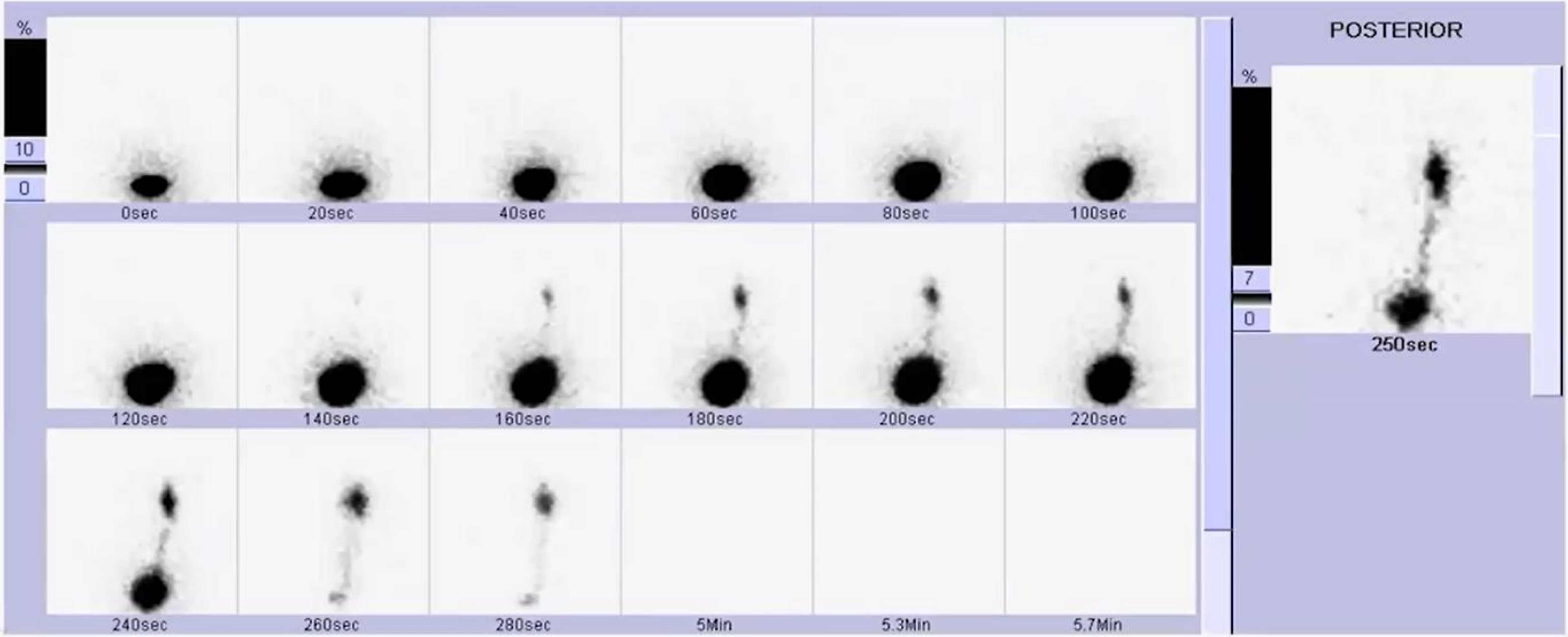
- F/U for VUR: possibility of spontaneous resolution

- Initial diagnosis in older girls

- Siblings screening

4 year-old boy with right vesicoureteral reflux





Evaluation of vesicoureteric reflux and pyelonephritis

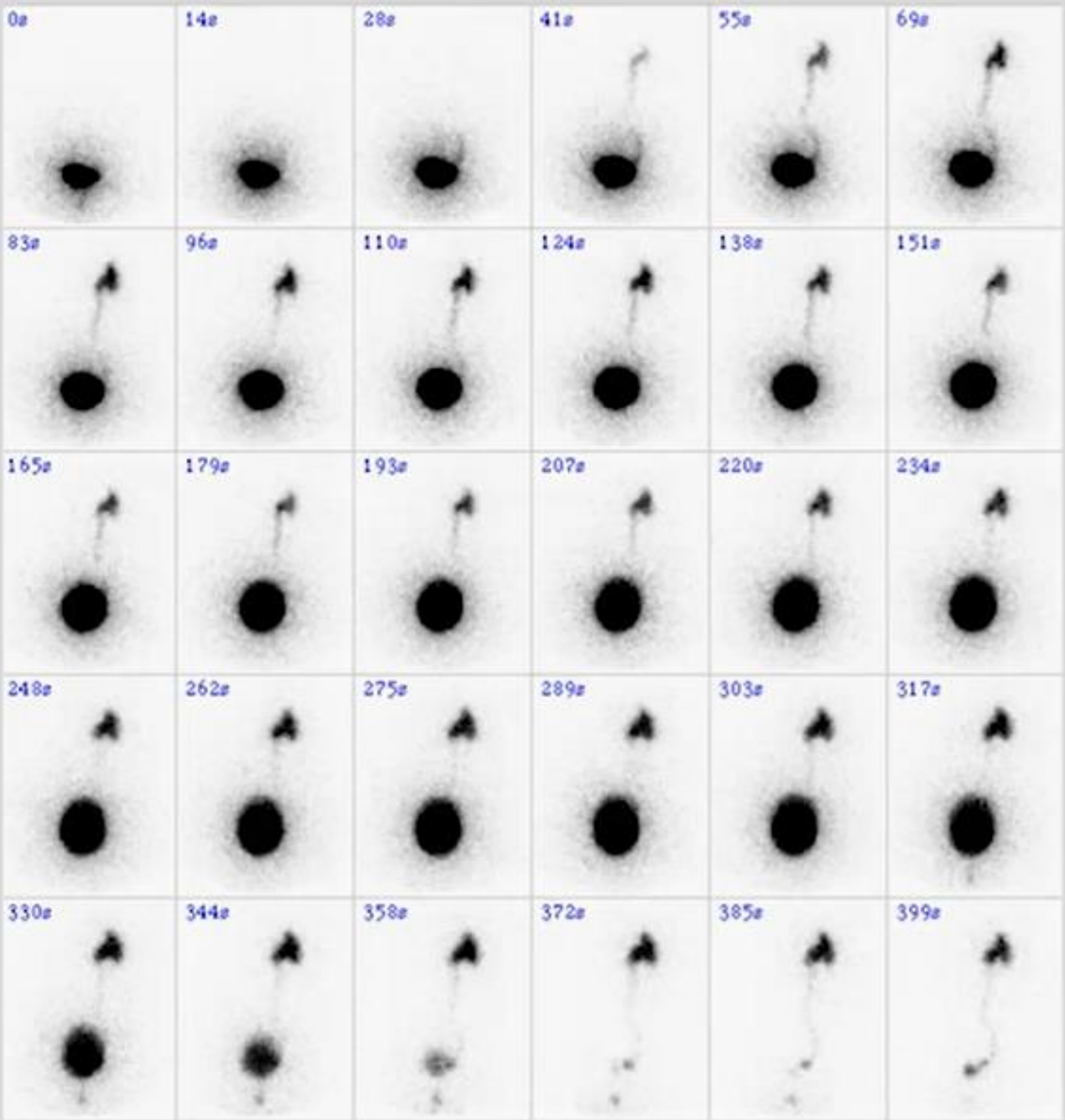
BOTTOM-UP

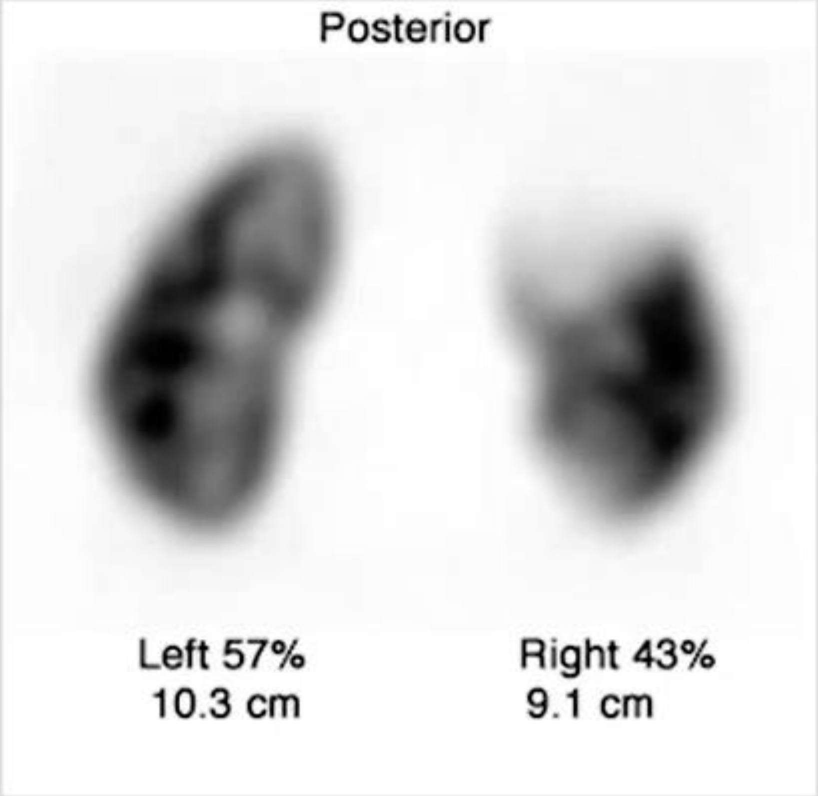
- Assess for reflux with fluoroscopic VCUG
- Follow reflux with radionuclide cystography
- If recurrent infections, assess for scarring with DMSA

TOP-DOWN

- Assess for renal scarring with DMSA/ultrasound
- If scarring, assess for VUR with fluoroscopic VCUG
- If recurrent infections, follow reflux with RNC

Right VUR + PN upper pole of right kidney





Bladder Capacity Consideration:

- For children older than 2 years, expected bladder capacity can be estimated by the formula:

$$(age+2) \times 30$$

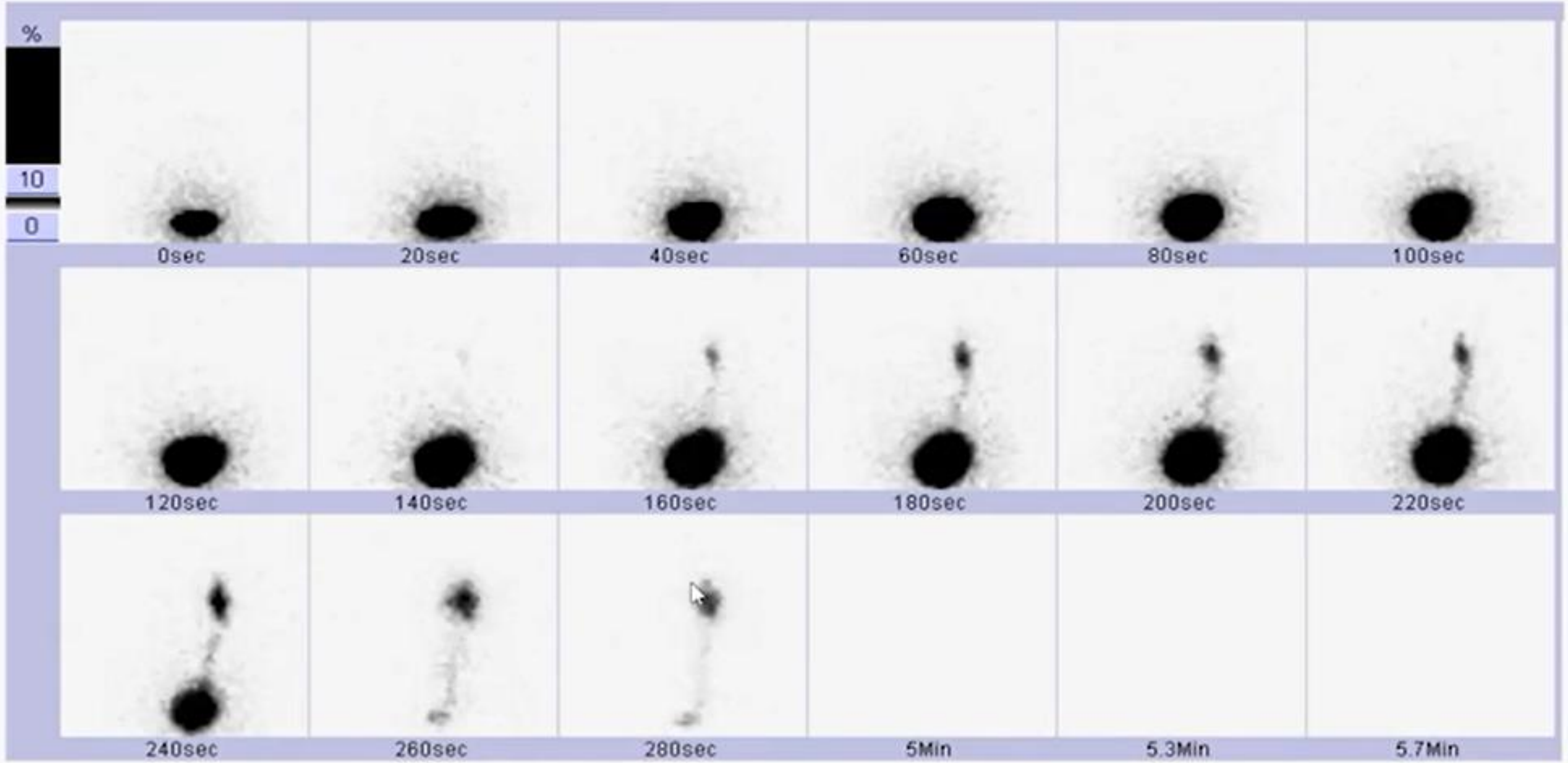
- For children younger than 2 years, the formula is:

$$38 + (2.5 \times \text{age in months})$$

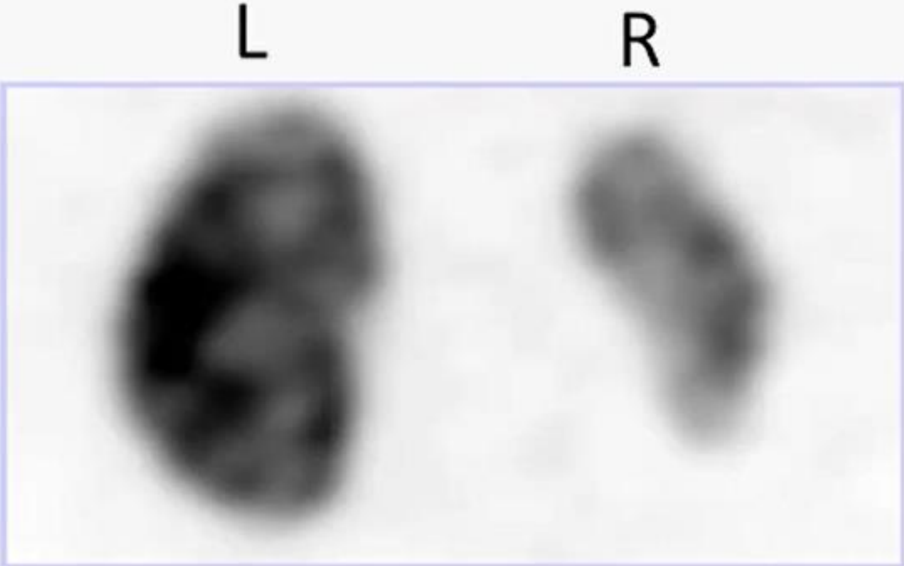
Direct cystography <u>cannot</u> be performed in children with:

- **Pelvic kidney**
- **Low-lying ectopic kidney**

4 year-old boy with right vesicoureteral reflux



Radionuclide Cystogram

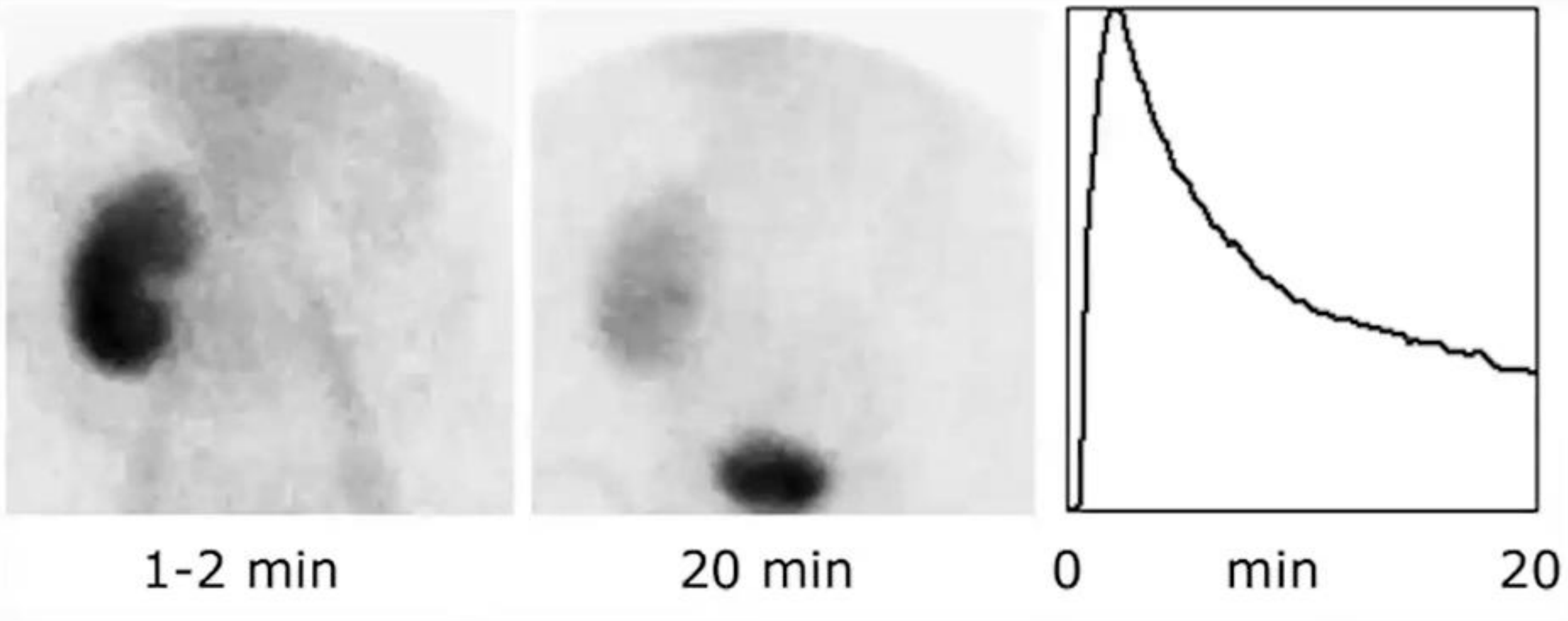


^{99m}Tc-DMSA

Cortical Renal Scan

Renal Transplant Evaluation

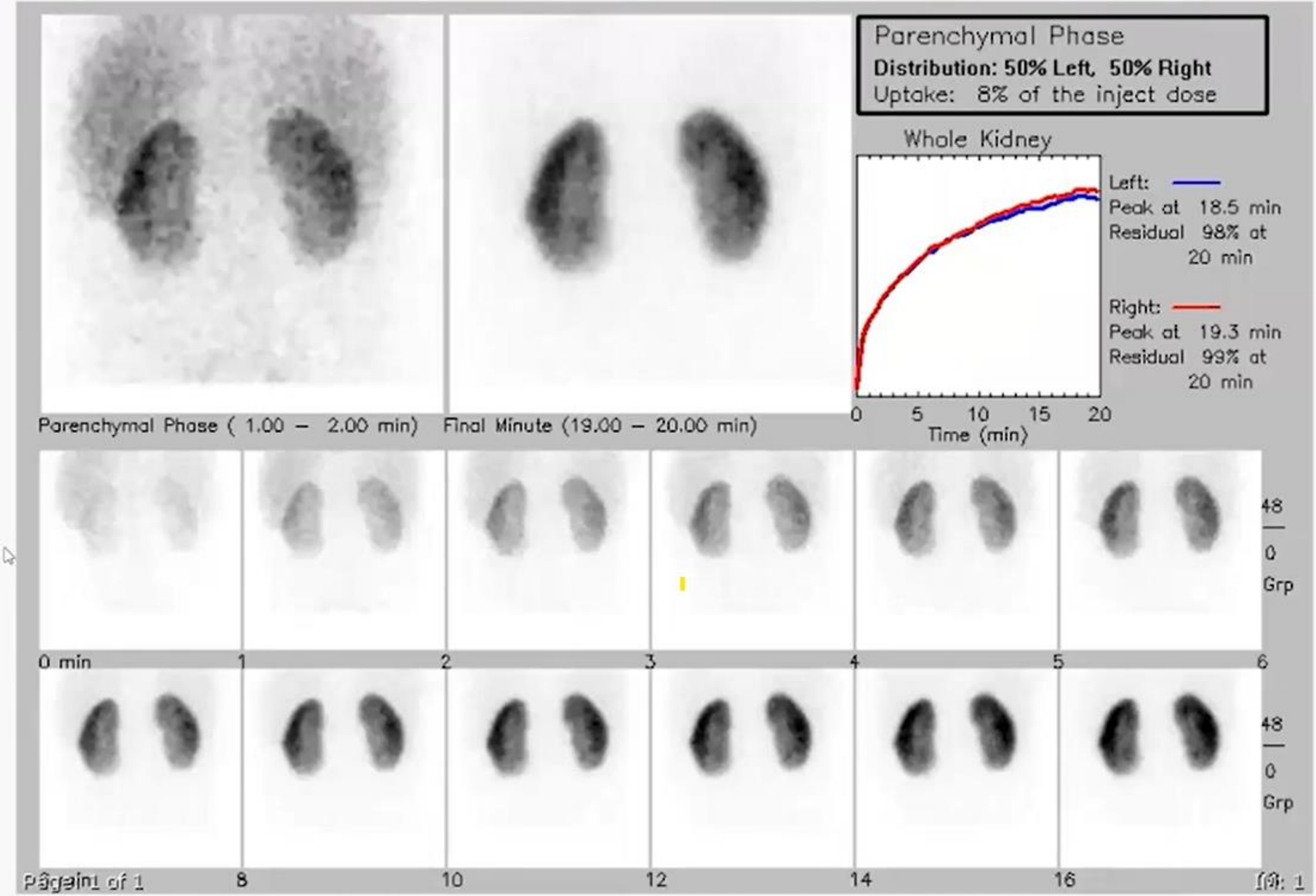
Renal transplant evaluation



Heterotopic living donor transplant, right lower quadrant

Assess: perfusion, function, drainage, leaks

17 year-old male with acute tubular necrosis



Cortical retention of tracer (MAG3)

VASCULAR

Dehydration/hypovolemia

Hypotension

Ischemia

Arterial stenosis

- current
- prior

Medication (ACE inhibitor)

Infection

RENAL

Renal failure

- acute renal failure (ATN)
- transplant rejection
- chronic renal failure

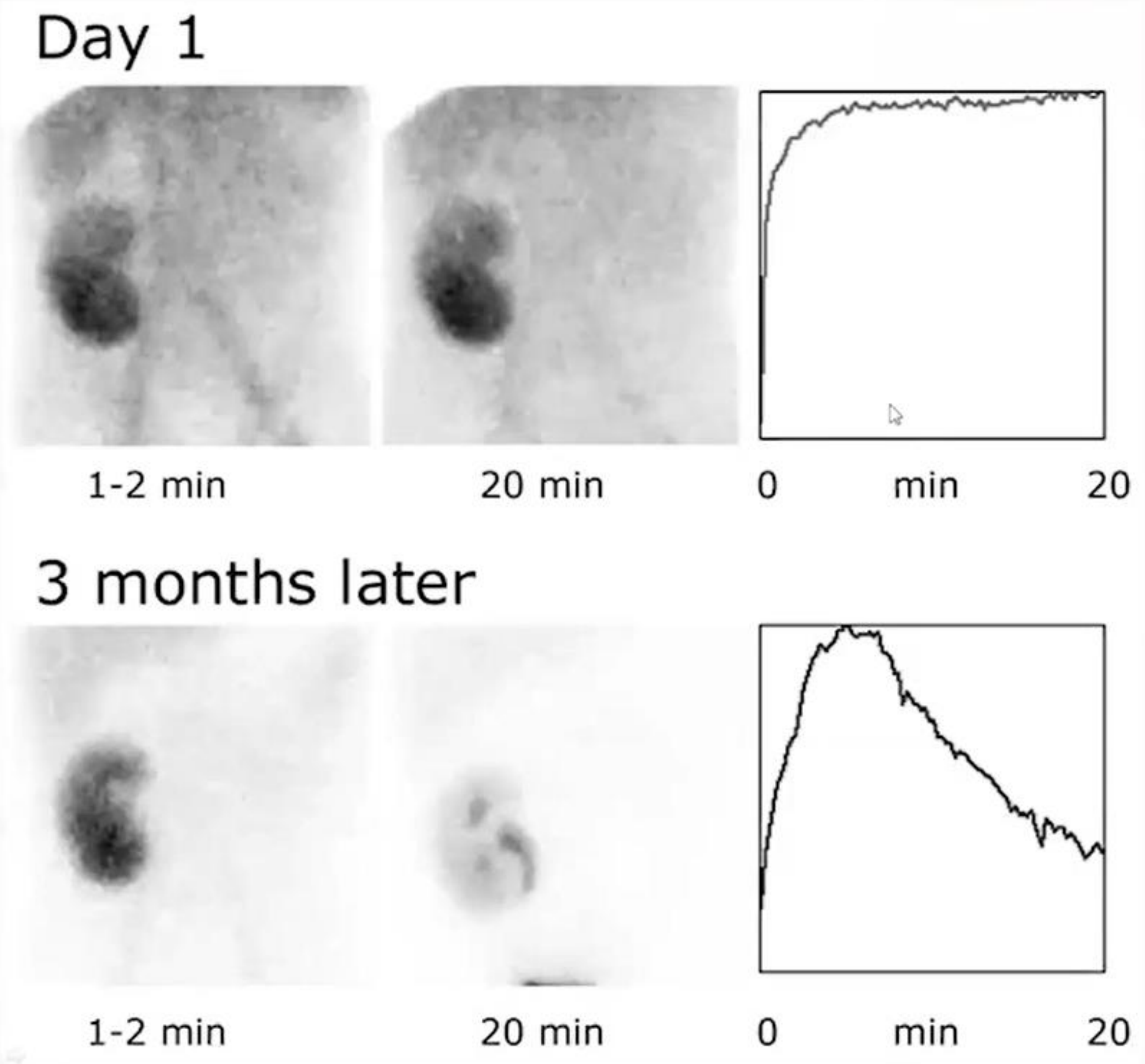
Medication (nephrotoxic drugs)

Recent iodinated contrast — Perform with 24 delay

Radiation therapy

Infancy (immaturity) — If possible: delay 2 months

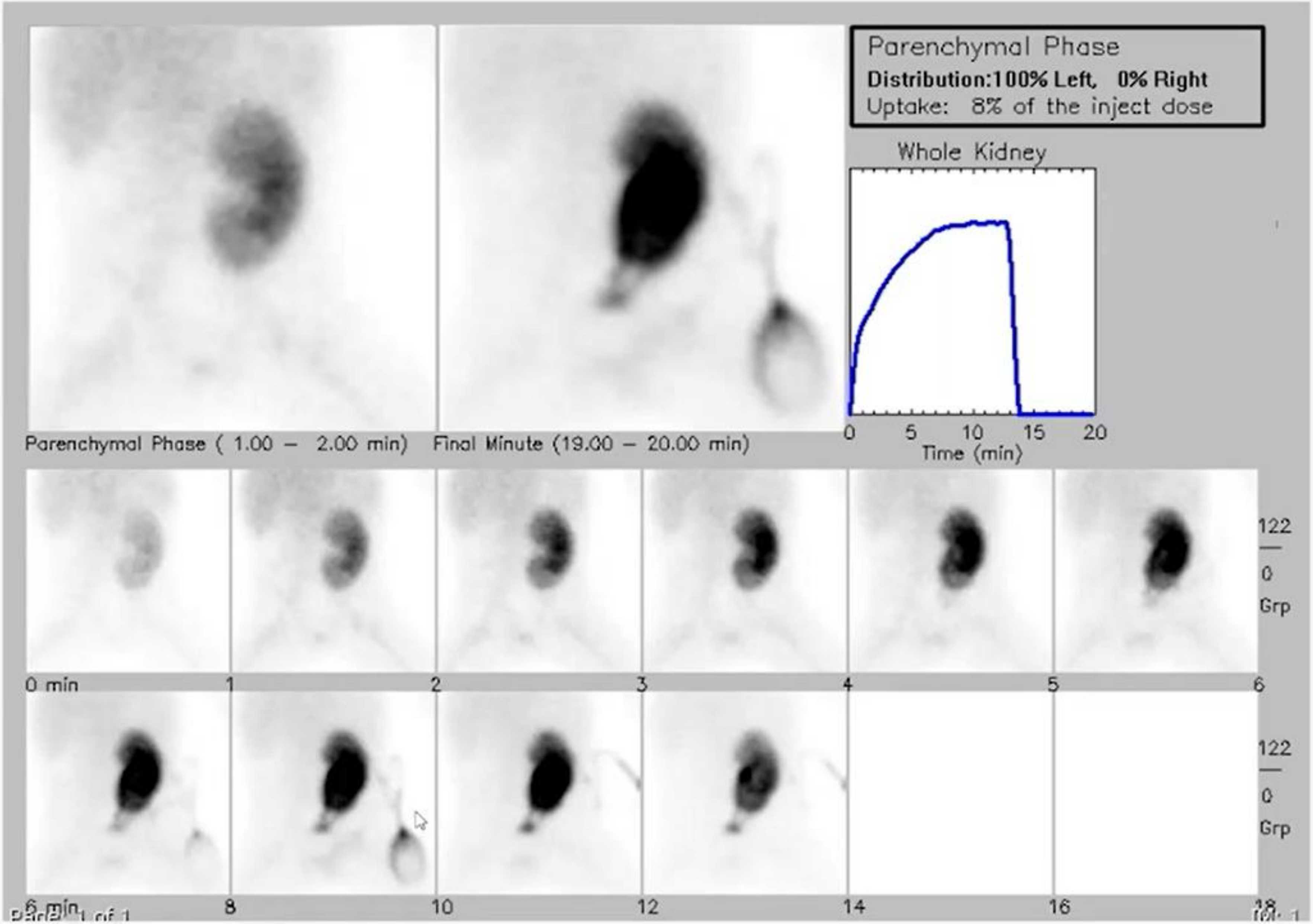
Renal transplant evaluation



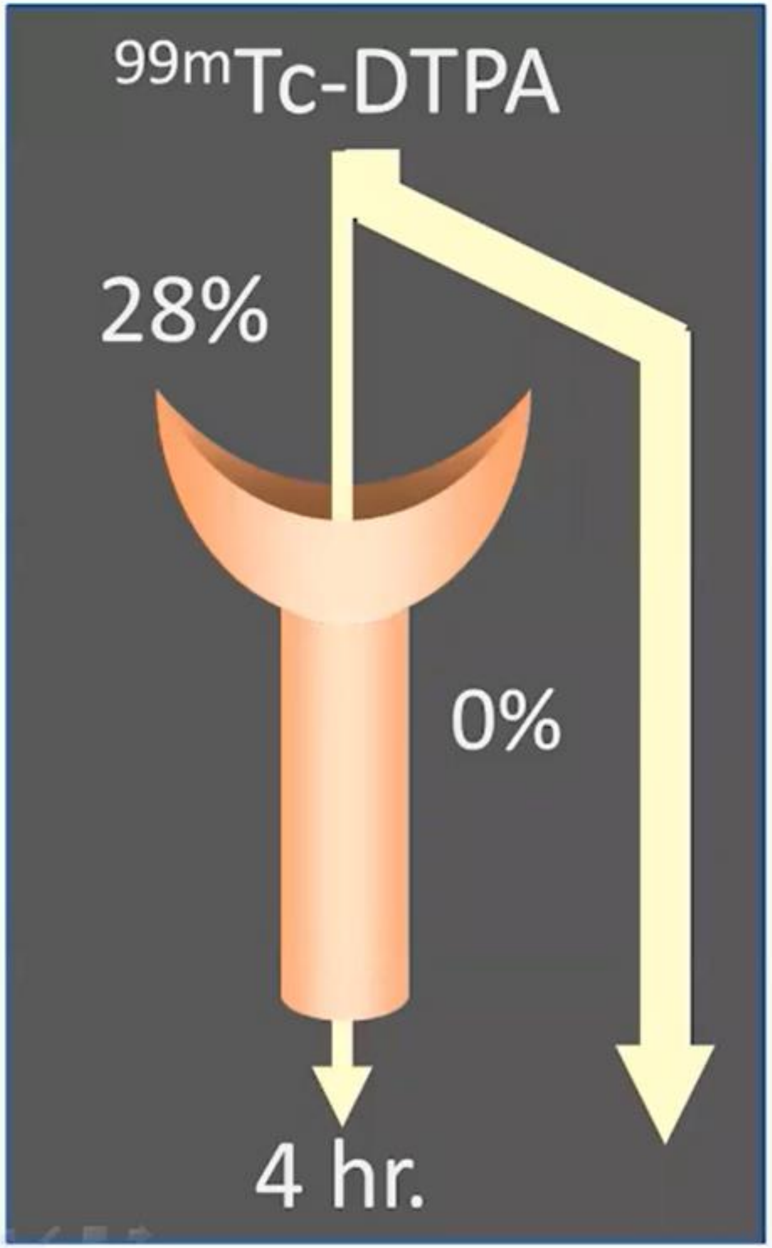
Deceased donor transplant, right lower quadrant

ATN

5 year-old boy, renal transplant leak

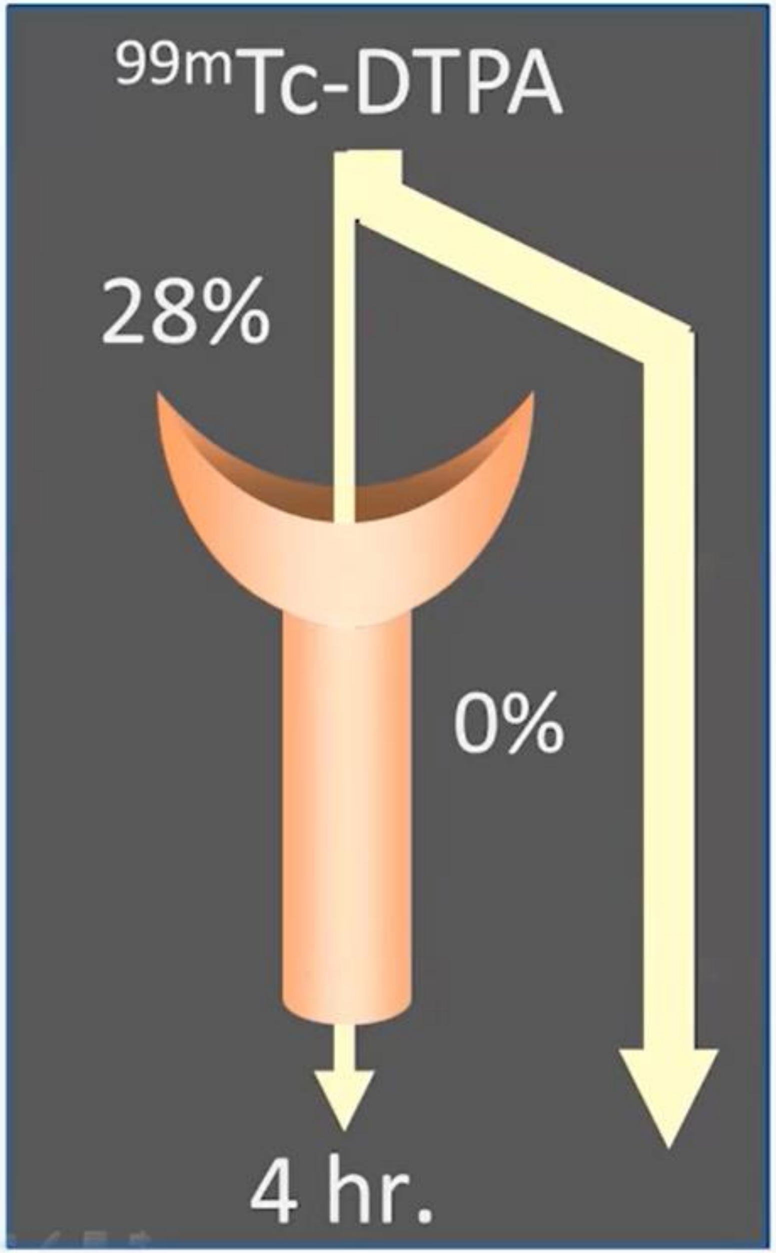


Assessing glomerular function (GFR)

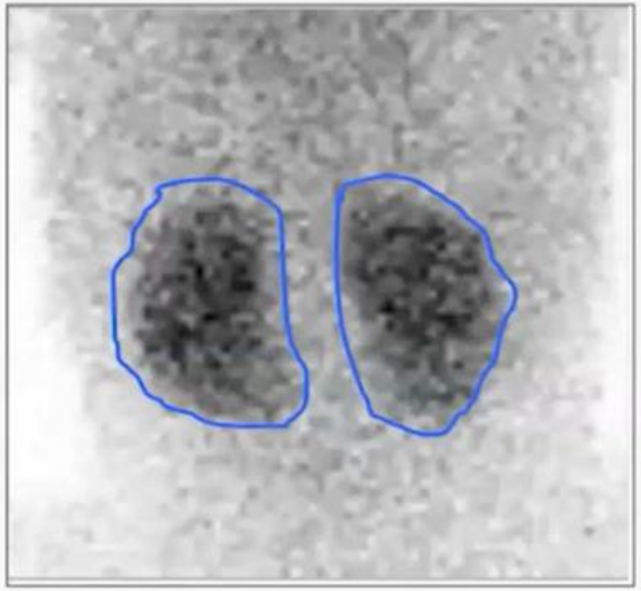


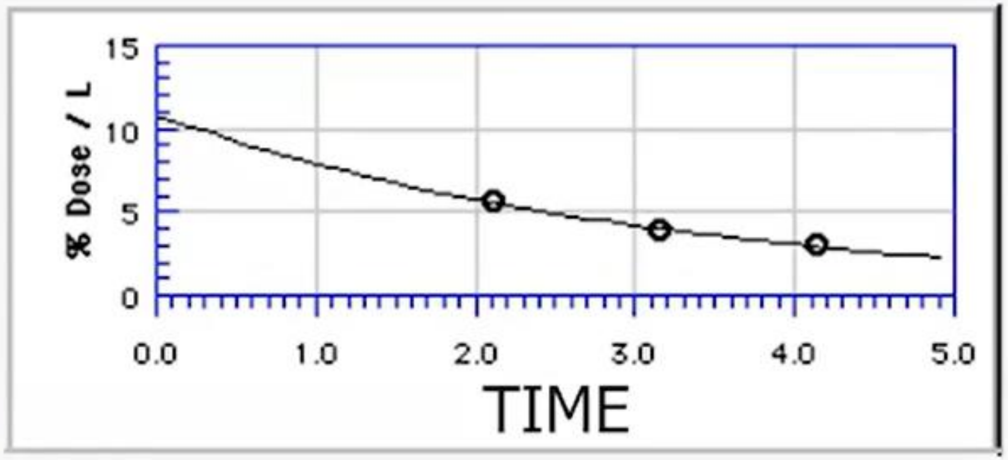
^{99m}Tc-DTPA is excreted entirely by glomerular filtration

Radionuclide glomerular function (GFR)



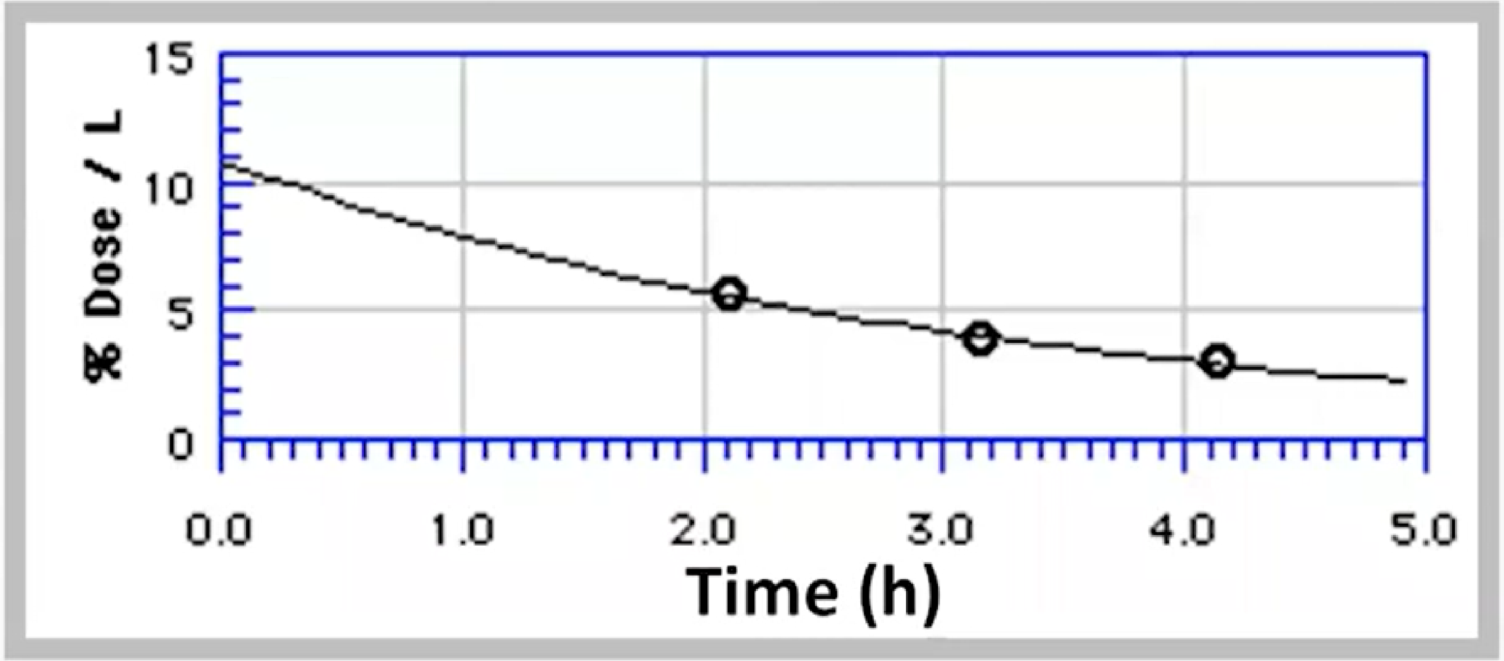
ROI (Gates)	*DIRECT*
No blood draw	2-4 Blood samples
Less precise	More precise





Radionuclide GFR

- Glomerular filtration / clearance of ^{99m}Tc-DTPA
- Blood sampling at ~2, 3, and 4 hours



$$C(t) = C_0 e^{\ln(2)t/T}$$

- Patient preparation: well hydrated, concurrent drugs

Radionuclide GFR

- Advantages:
  - direct measure of glomerular filtration
  - faster and more reliable than 24-hour urine collections
  - more reliable than estimates from serum Cr
    - no pediatric standards for using CR
  - measure day-to-day variability (during chemotherapy)
- Disadvantages
  - radiation exposure (~0.1 mSv)
  - biological fluids in nuclear medicine- CLIA compliant

THANK YOU