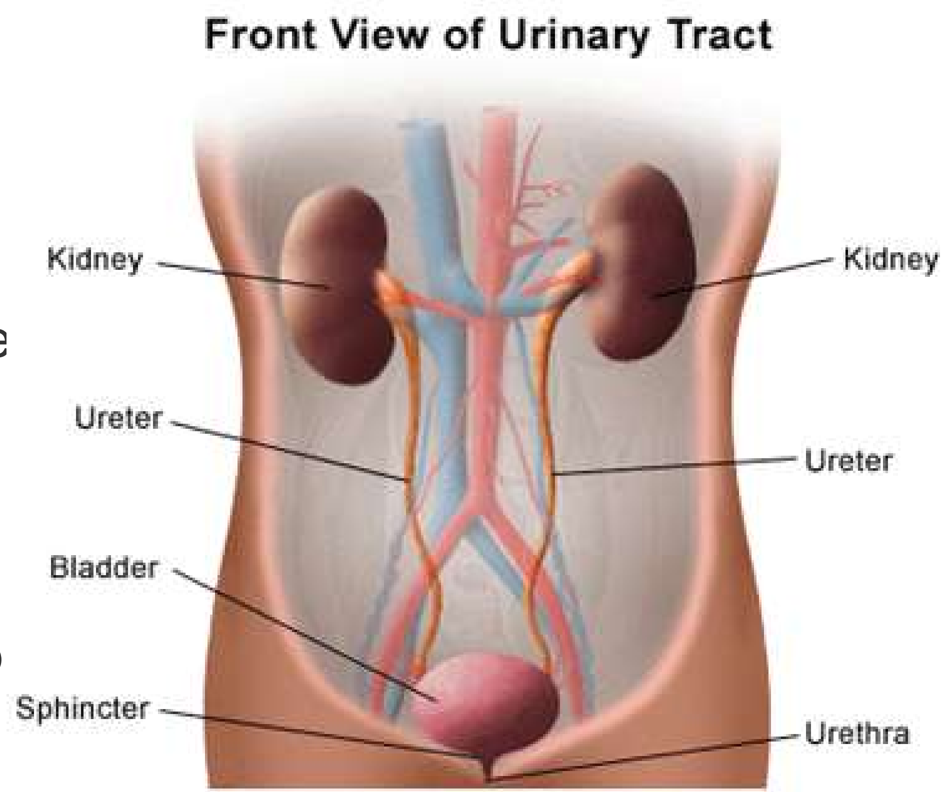
The Urinary System

Nuclear Medicine Scans: Analysis of uptake mechanism and imaging protocols

Anatomy of Kidney

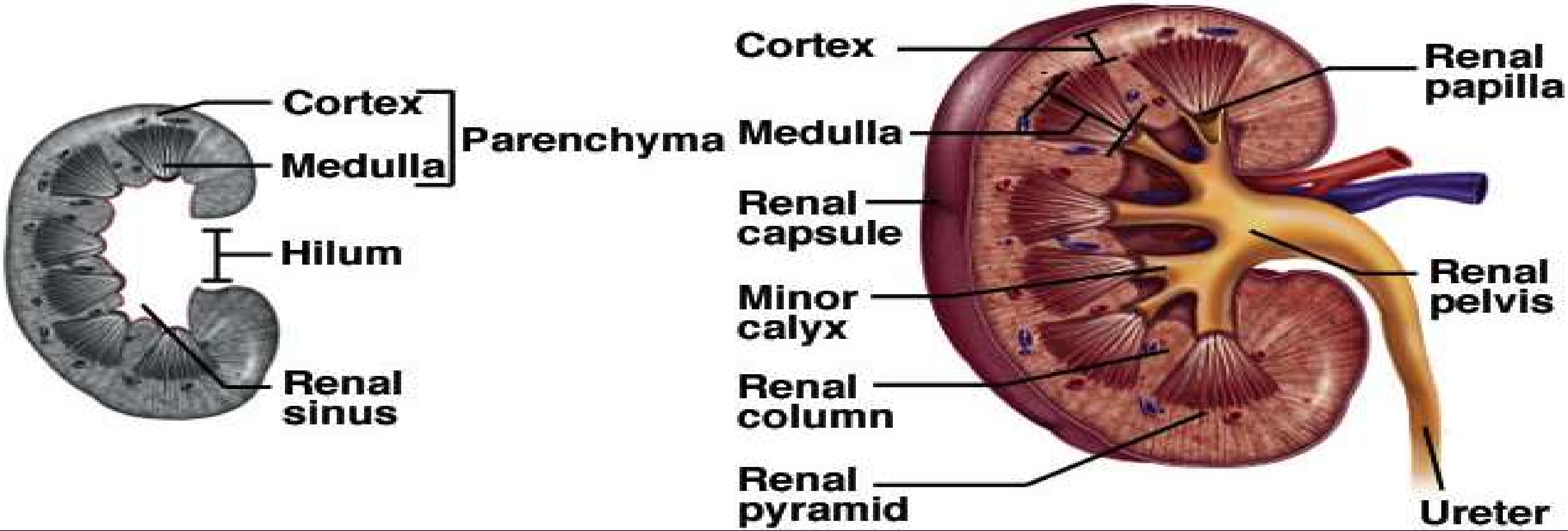
- Position, weight and size
  - retroperitoneal, level of T12 to L3
  - about 160 g each
  - about size of a bar of soap (12x6x3 cm)
- Shape
  - lateral surface - convex; medial - concave
- CT coverings
  - renal fascia: binds to abdominal wall
  - adipose capsule: cushions kidney
  - renal capsule: encloses kidney like cellop



Kidney Functions

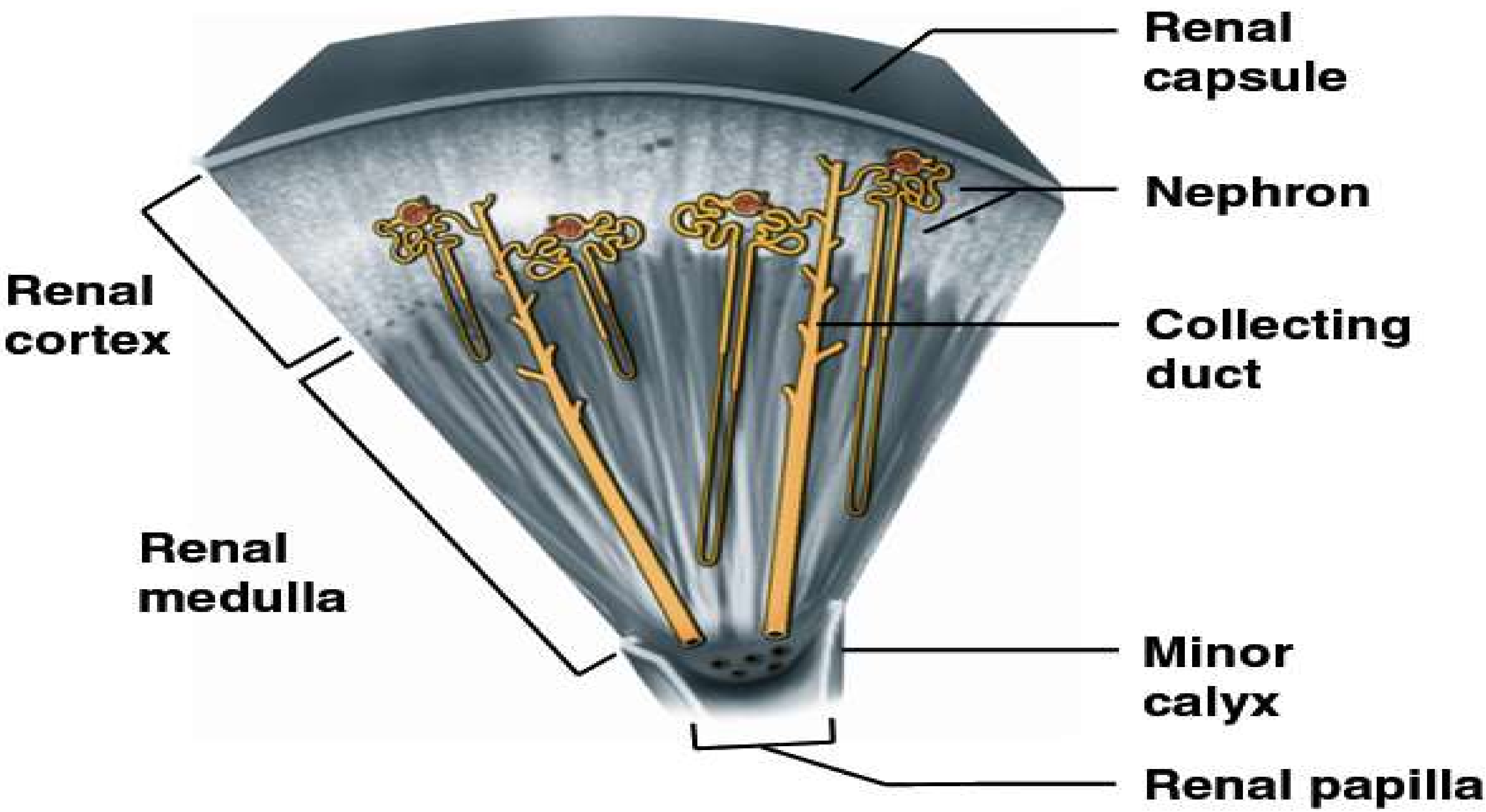
- Filters blood plasma, eliminates waste, returns useful chemicals to blood
- Regulates blood volume and pressure
- Regulates osmolarity of body fluids
- Secretes renin, activates angiotensin, aldosterone
  - controls BP, electrolyte balance
- Secretes erythropoietin, controls RBC count
- Regulates P_{CO_2} and acid base balance
- Detoxifies free radicals and drugs
- Gluconeogenesis

Anatomy of Kidney



- Renal cortex: outer 1 cm
- Renal medulla: renal columns, pyramids - papilla
- Lobe of kidney: pyramid and it's overlying cortex

Lobe of Kidney



Path of Blood Through Kidney

- Renal artery

  → interlobar arteries **(up renal columns, between lobes)**

  → arcuate arteries (over pyramids)

  → interlobular arteries (up into cortex)

  → afferent arterioles

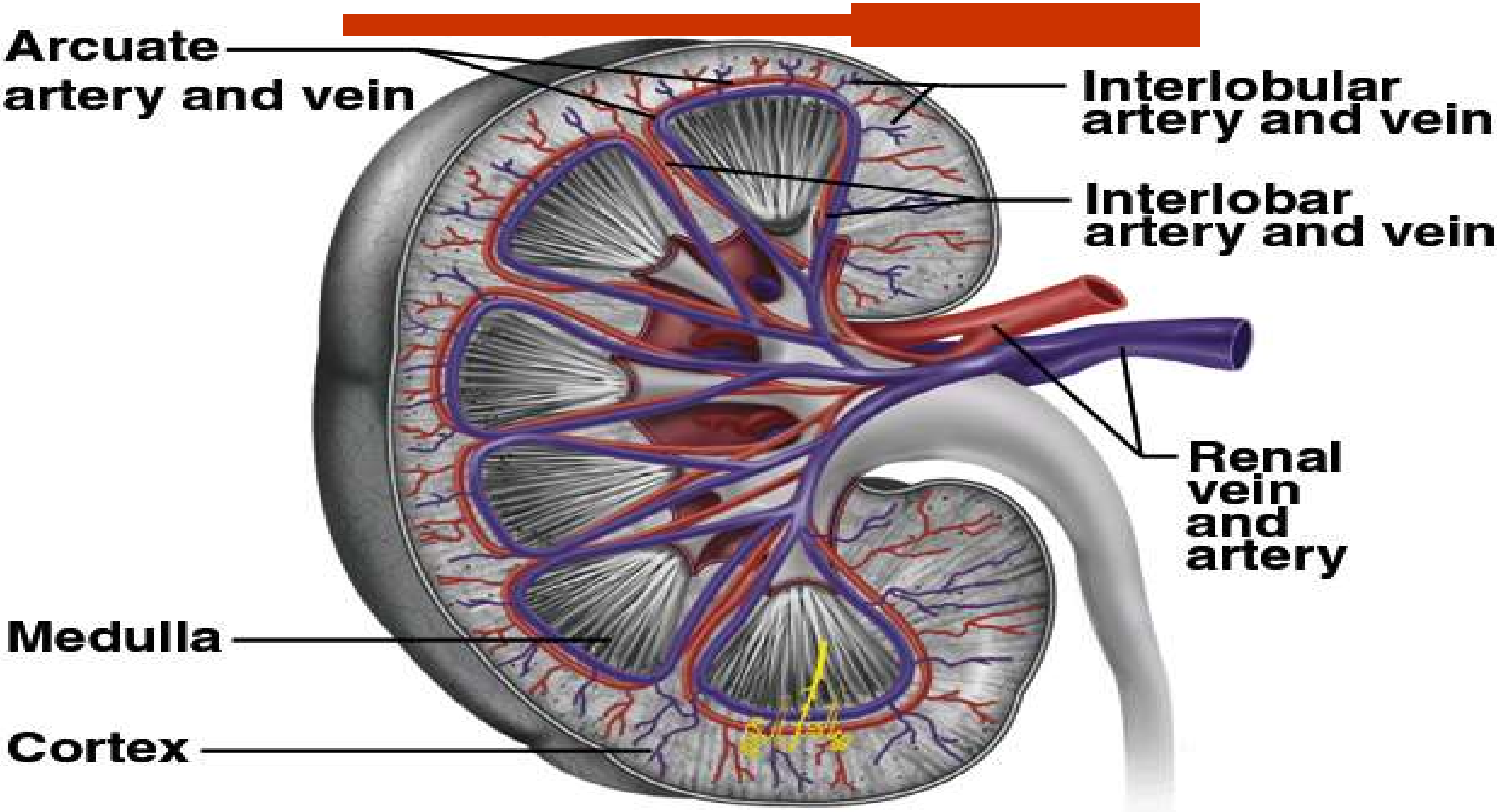
  → glomerulus (cluster of capillaries)

  → efferent arterioles (near medulla → vasa recta)

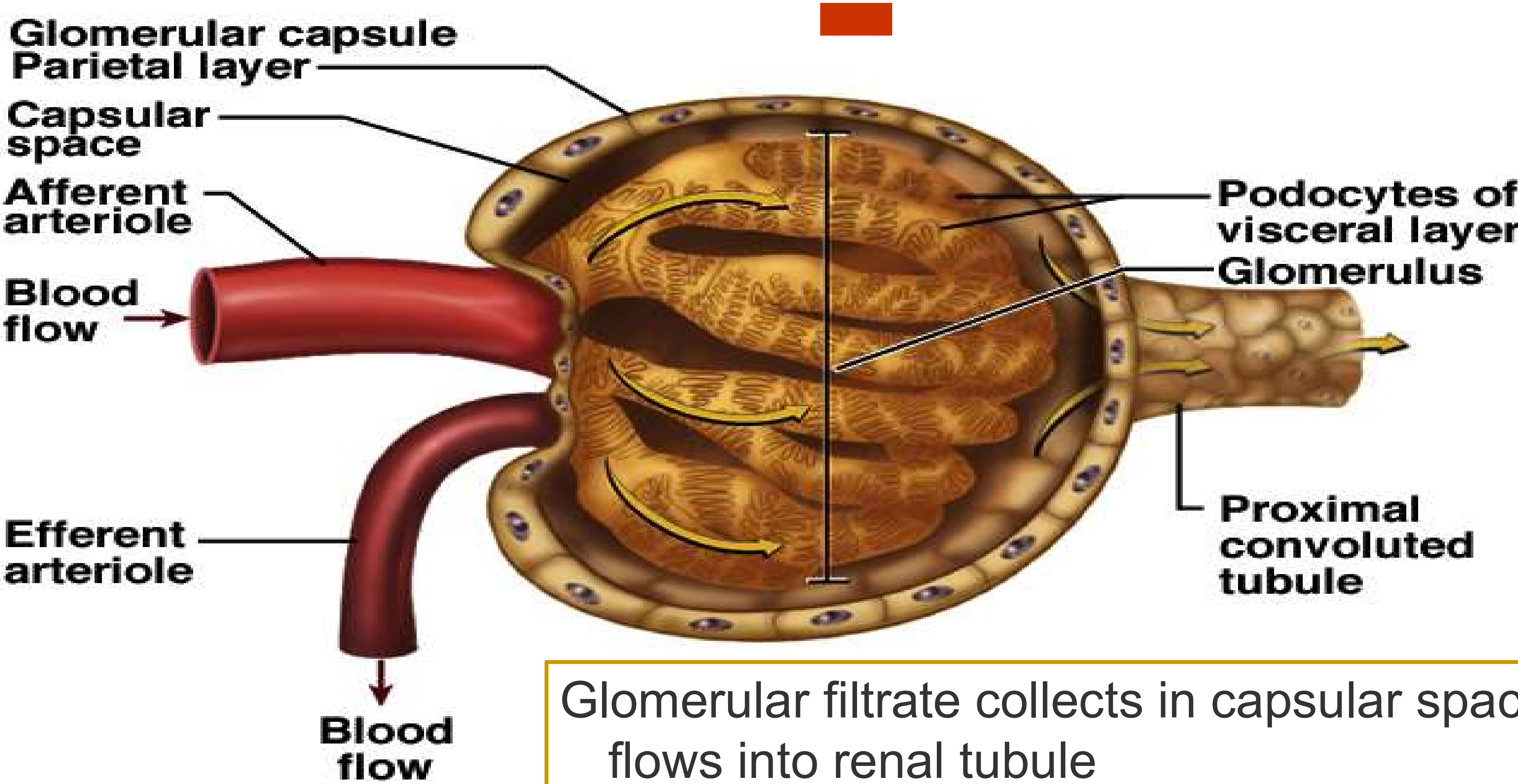
  → peritubular capillaries

  → interlobular veins → arcuate veins → interlobar veins
- Renal vein

Blood Supply Diagram



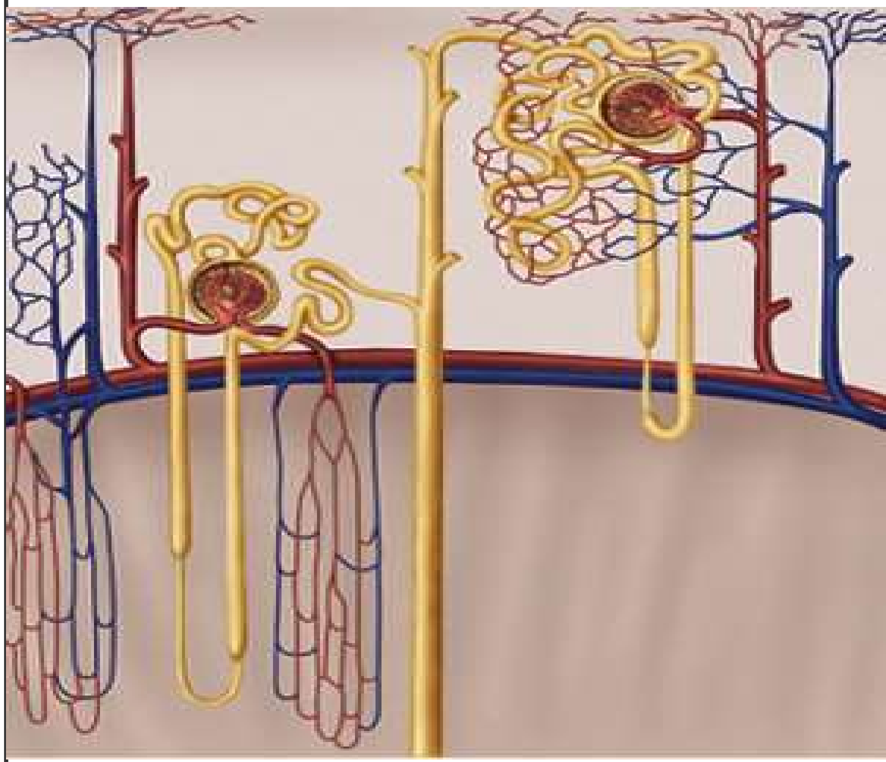
Renal Corpuscle



Glomerular filtrate collects in capsular space, flows into renal tubule

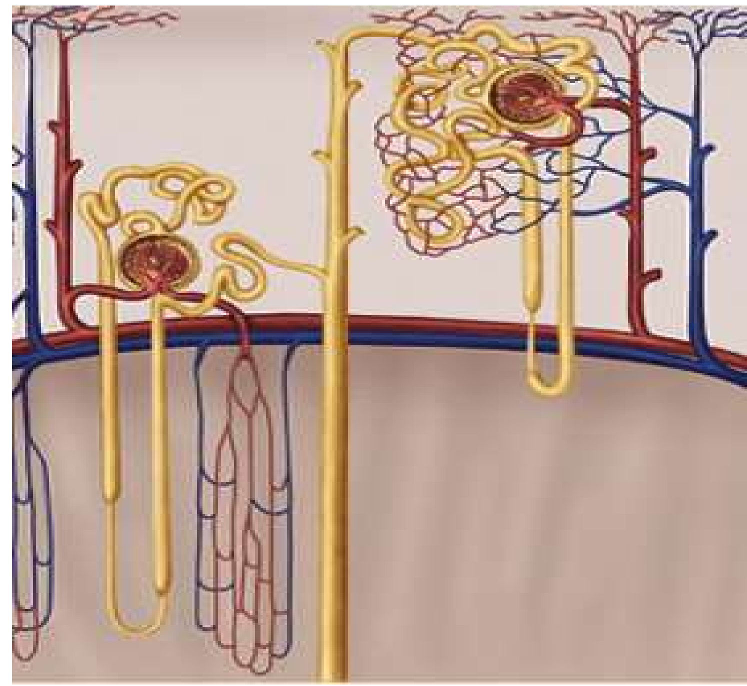
Renal (Uriniferous) Tubule

- Proximal convoluted tubule (PCT)
  - longest, most coiled, simple cuboidal with brush border
- Nephron loop - U shaped; descending + ascending limbs
  - **thick segment** (simple cuboidal) initial part of descending limb and part or all of ascending limb, active transport of salts
  - **thin segment** (simple squamous) very water permeable
- Distal convoluted tubule (DCT)
  - cuboidal, minimal microvilli

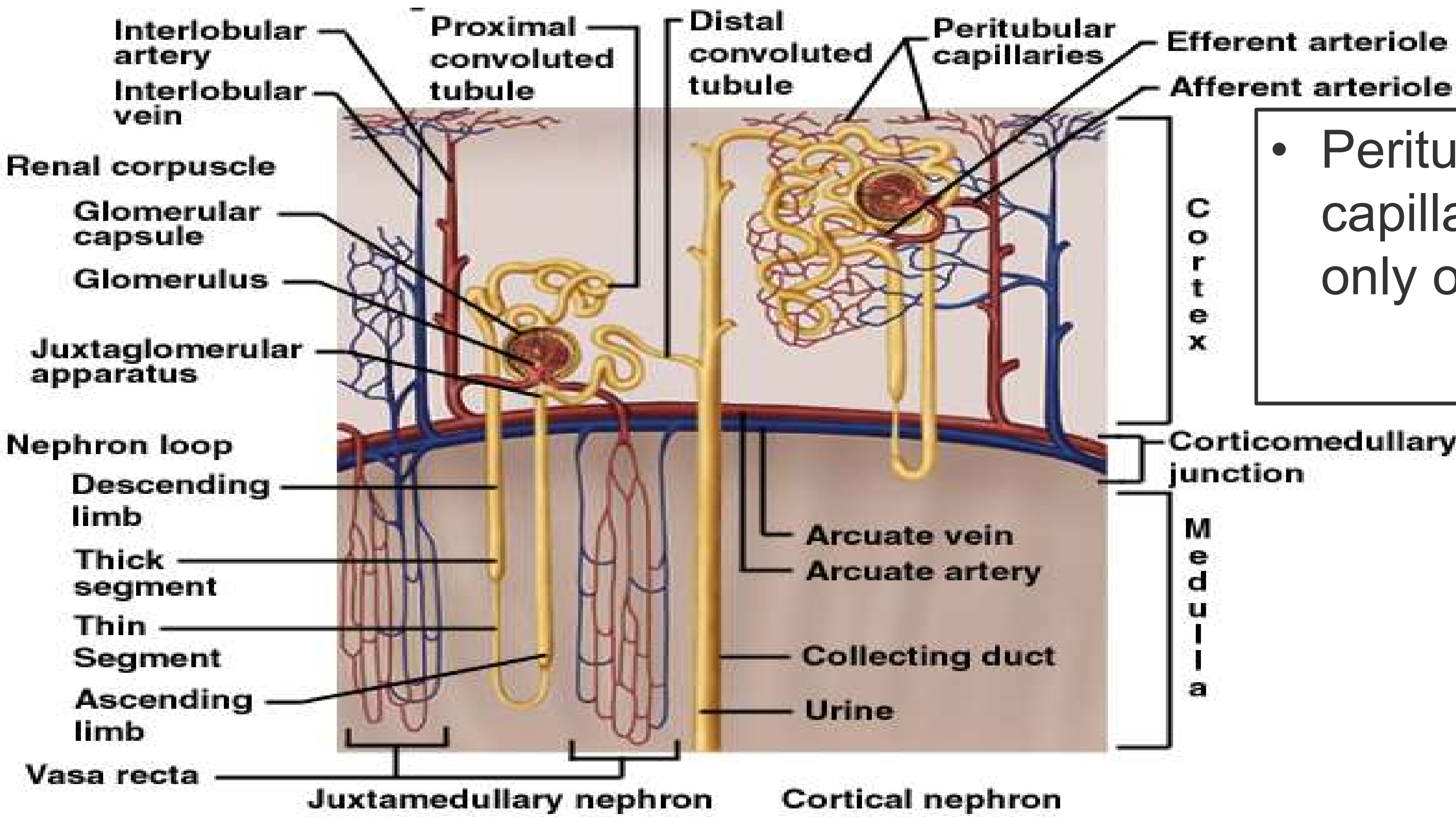


Renal (Uriniferous) Tubule

- Juxtaglomerular apparatus: DCT, afferent, efferent arterioles
- Collecting duct: several DCT's join
- Flow of glomerular filtrate:
  - glomerular capsule → PCT → nephron loop → DCT → collecting duct → papillary duct → minor calyx → major calyx → renal pelvis → ureter → urinary bladder → urethra

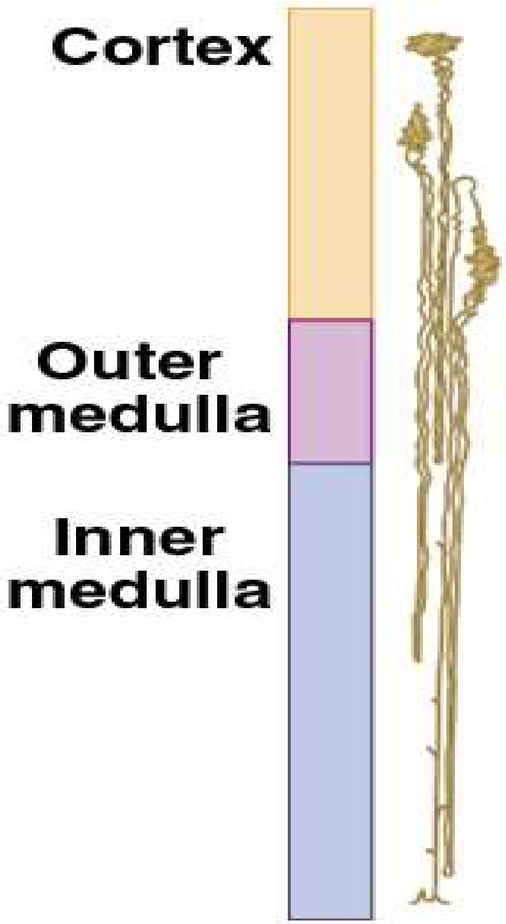


Nephron Diagram



- Peritubular capillaries shown only on right

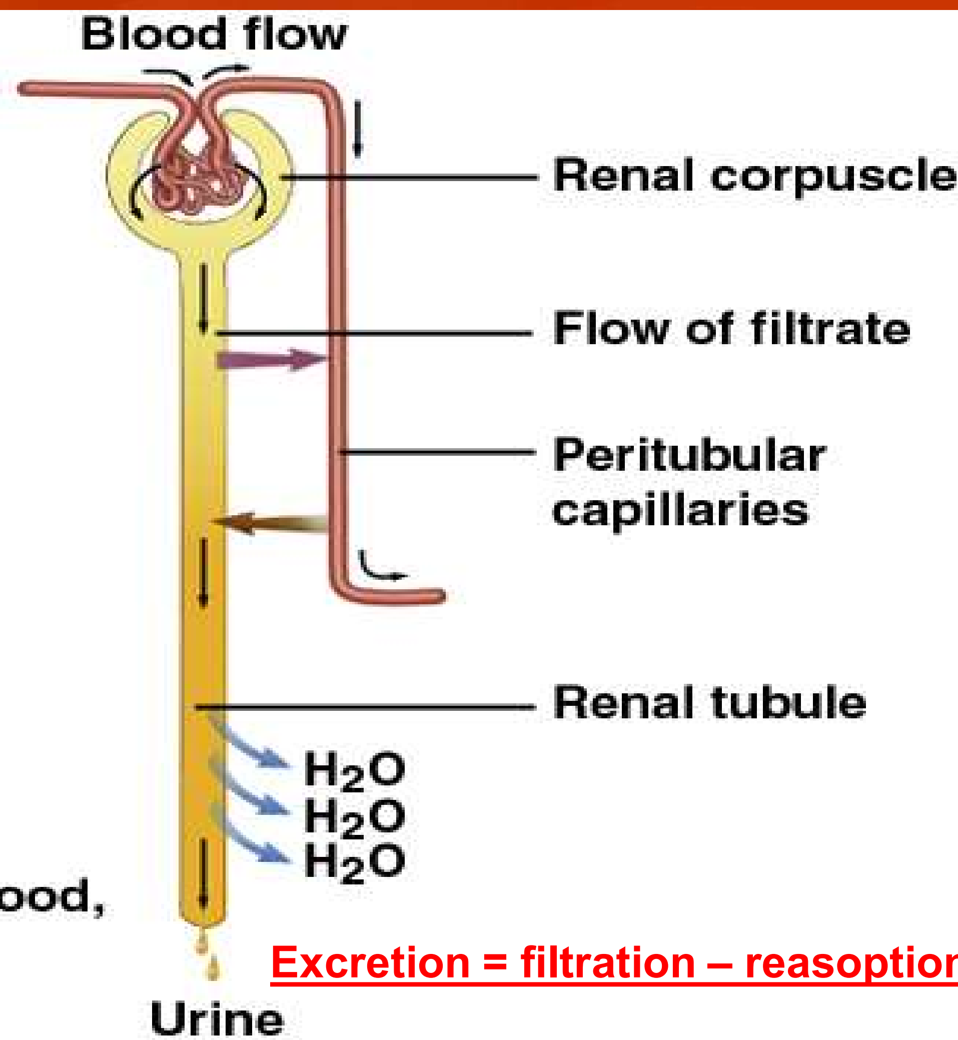
Nephrons



- True proportions of nephron loops to convoluted tubules shown
- Cortical nephrons (85%)
  - short nephron loops
  - efferent arterioles branch off peritubular capillaries
- Juxtamedullary nephrons (15%)
  - very long nephron loops, maintain salt gradient, helps conserve water
  - efferent arterioles branch off vasa recta, blood supply for medulla

Urine Formation Preview

1. **Glomerular filtration**
   Creates a plasmalike filtrate of the blood
2. **Tubular reabsorption**
   Removes useful solutes from the filtrate, returns them to the blood
3. **Tubular secretion**
   Removes additional wastes from the blood, adds them to the filtrate
4. **Water conservation**
   Removes water from the urine and returns it to blood, concentrates wastes



Excretion = filtration – reasoption + secretion

Renal Radiopharmaceuticals

Dynamic :

- Rapidly excreted radiopharmaceuticals that are useful for functional studies

Morphological:

- Retained radiopharmaceuticals that are useful for morphological studies

Indications Dynamic studies

1. measurement of glomerular filtration rate (GFR 125ml/min)
2. measurement of effective renal plasma flow (600ml/min)
3. evaluation of renal artery perfusion
4. visualisation of the collecting system
5. evaluation of renal transplant rejection
6. renal flow studies in patients with poor renal function

Excretion Mechanisms

	GF	TS	TF
Tc-99m DTPA	>95%		
Tc-99m MAG3	<5%	95%	
I-131 OIH	20%	80%	
Tc-99m GHA	40%-60%		20%
Tc-99m DMSA	some		60%

Semin NM Apr.92

Renal Radiopharmaceuticals

	Extract. fraction	Clearance
Tc-99m DTPA	20%	100-120 ml/min
Tc-99m MAG3	40-50%	~ 300 ml/min
I-131 OIH	~100%	500-600 ml/min

Choosing Renal Radiotracers

Clin. Question	Agent
Perfusion	MAG3, DTPA, GHA
Morphology	DMSA, GHA
Obstruction	MAG3, DTPA, OIH
Relative function	All
GFR quantitation	Cr-51 EDTA, DTPA
ERPF quantitation	MAG3, OIH

^{99m}Tc-DTPA

- 100% glomerular filtration; no reabsorption; no secretion
- agent of choice for quantification of GFR
- normal adult dose 370-550MBq
- low protein binding (<5%)
- rapid plasma clearance into extracellular space and through kidneys,
- rapid distribution throughout extracellular fluid space,
- concentration in kidneys reaches peak in 3-4 min post I.V. injection with 50% excreted from kidneys within 2 hours and 95% by 24 hours
- critical organ is the bladder (23mGy/MBq)
- cold kit form with stannous as reducing agent
- radiochemical purity very important for GFR determination (Use ITLC-SG)

$^{123}I/^{131}I$-iodohippurate

- 80% renal tubular excretion; 20% glomerular filtration
- after injection; image 1-2 min intervals for 30 min.
- use has greatly declined since the introduction of MAG-3
- indication: quantitation of Effective Renal Plasma Flow (ERPF) a diagnostic indicator of renal tubular function.

^{99m}Tc-MAG$_3$

- First ^{99m}Tc renal agent to be excreted by tubular secretion as an organic anion
- Although 99mTc-MAG3 is highly plasma protein bound following I.V. injection, the protein binding (85-90%) is reversible and the tracer is rapidly excreted by the kidneys via active tubular secretion.
- Extraction efficiency approx 45-55%. Peak renal activity at 4 min and within 30 minutes 70 % of the dose is excreted by the kidneys, and by 3 hours 95% of the dose is in the bladder.
- The tubule transport system has a lower affinity for 99mTc-MAG3 than iodohippuran. 1-3% of the dose is excreted via hepatobiliary system.
- Normal dose is 185-370MBq and the critical organ is the bladder.

Retained/slowly exreted agents

- Retained in the kidney allowing morphological imaging of the kidney
- Used mainly in paediatric studies

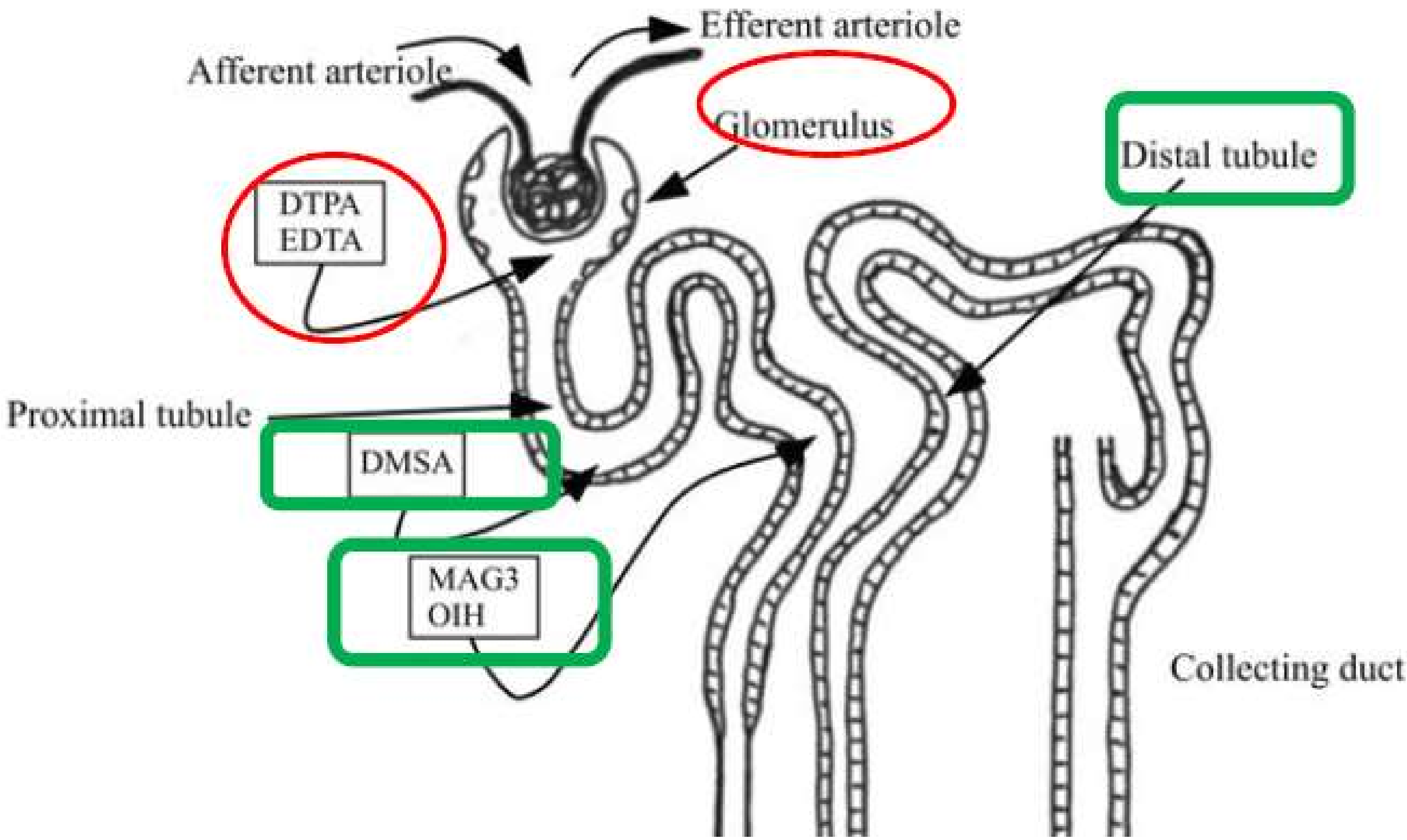
Indications

- Anatomical evaluation of the renal cortex
- Detection of space-occupying lesions such as tumours, cysts and abscesses.

^{99m}Tc-DMSA

- Following IV injection, 75-90% bound to plasma proteins
- DMSA is taken up into the renal cortex (cortex:medulla ratio 22:1)
- 1 hour after administration 25-35% of the 99mTc-DMSA activity is localised in the kidneys, while after 2-3 hours 40-50%. Simultaneously, 25% of the administered activity is excreted with the urine during the first hour.
- [99mTc-(DMSA)2] is taken up by the kidneys in form bound to the plasma proteins. One of the ligands is replaced by an –SH group of the receptor in the tubules (especially in the proximal ones), a [99mTc-(DMSA)-receptor] complex is formed, one DMSA molecule gets free and is excreted with the urine.
- Finally, 99mTc-(DMSA) bound in the kidneys is excreted with the urine.
- The total body retention of DMSA is much longer, giving it the highest radiation dose to the patient of all the renal imaging agents.

Summary


Efferent arteriole
Afferent arteriole
Glomerulus
DTPA
EDTA
Distal tubule
Proximal tubule
DMSA
MAG3
OIH
Collecting duct

Interventional Agents

- Interventional pharmaceuticals cause alterations in the physiological process
- Provide additional information.
- It increases the specificity and sensitivity of the study.

- **Frusemide (Lasix)**

  To evaluate obstructive uropathy. It is a loop diuretic which inhibits reabsorption of electrolytes, primarily sodium in the ascending limb of the loop of Henle as well as the proximal and distal tubules resulting in increased excretion of sodium, chloride, potassium and water. It produces diuresis within 5 min, a peakat 20 min and a duration of 2 hours

- **Captopril**

  To evaluate renovascular hypertension. Angiotensin II vasoconstricts efferent arterioles to maintain high filtration pressure in the glomeruli.

  ACE inhibitors stops the conversion of Angiotensin I to Angiotensin II ---> no vasoconstriction --->GFR decreases with increase in ERPF

Basic Renal Scan

Procedure

Patient Preparation

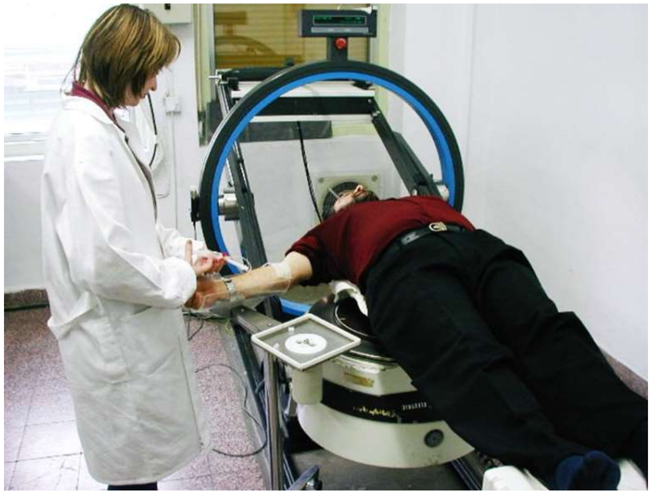
- Patient must be well hydrated
  - Give 5-10 ml/kg water (2-4 cups) 30-60 min. pre-injection
  - Can measure U - specific gravity (<1.015)
- Void before injection
- Void @ end of study

Basic Renal Scintigraphy

- Patient must be well hydrated
  - Give 5-10 ml/kg water (2-4 cups) 30-60 min. pre-injection
  - Can measure U - specific gravity (<1.015)
- Void before injection
- Void @ end of study

Acquisition:

- Pt. position: supine (motion, depth issues)
- Collimator: LEAP
- Image over injection site
- Flow (angiogram) : 2-3 sec / fr x 1 min
- Dynamic: 15-30 sec / frame x 20-30 min



Basic Renal Scintigraphy

<u>Pediatric nephrourology</u>

The neonate's kidney contains a million immature nephrons

GFR is very low at birth (about 30 ml/min/1.73m2)

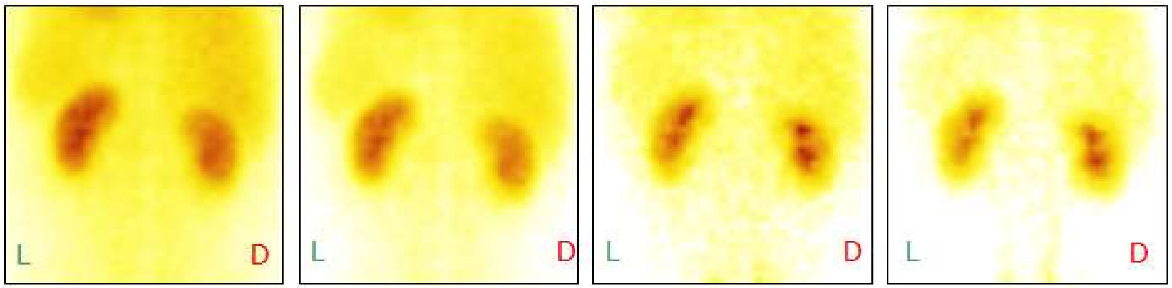
1 year of life - increases 3 times

2 years of age - 80% of the adult value

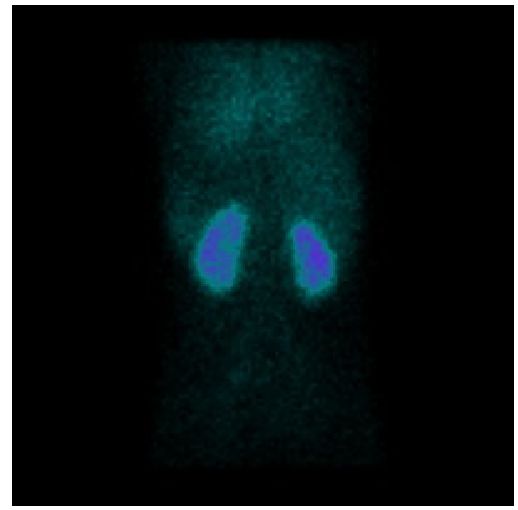
- 99mTc-DTPA - is not recommended for children under 2 (3) years of age due to the inability of immature glomeruli to take it up and high extrarenal activity (neonates and infants have a relatively large extravascular space).
- 99mTc-MAG3 – not recommended for children under 1 year, gives good kidney visualization (↑% binding to plasma proteins) and low extravascular distribution.

Dynamic study

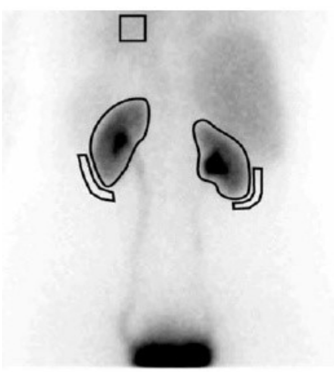
Qualitative analysis

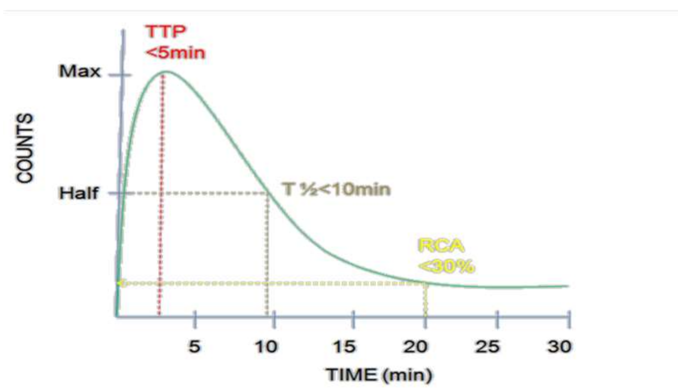


1-20 мин 1-5 мин. 10-12 мин. 15-20мин.



Quantitative analysis Relative (split) function ROI's





- 60 sec
  - Kidney vessels
- 2-5 min
  - Parenchimal uptake
- > 5 min
  - Excretory system

Dynamic study

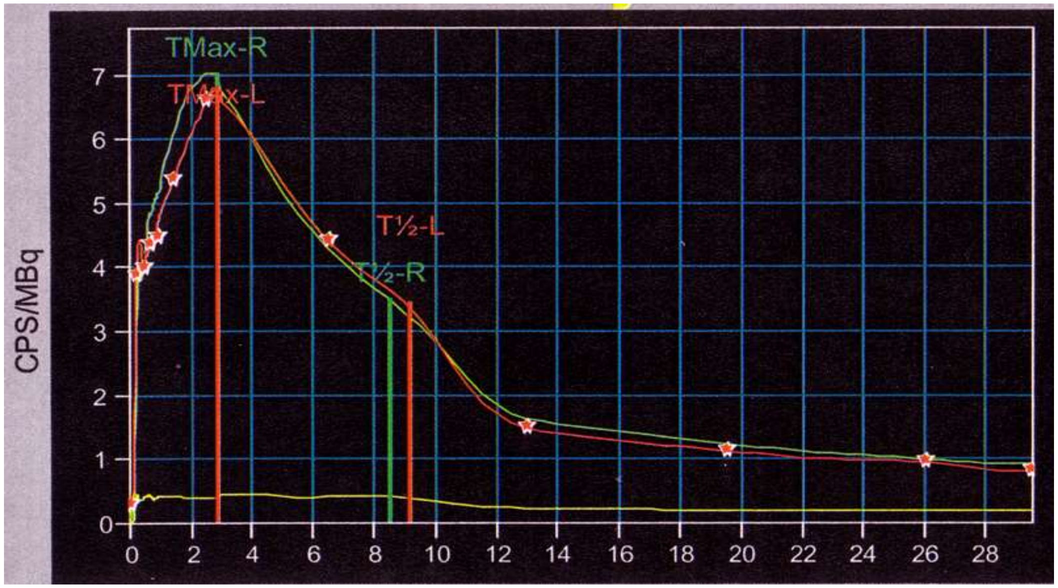


Table of Result Summary

Parameters	Left	Right	Total
Split Function (%)	55.1	44.9	
Kidney Counts (cpm)	34486	28151	62637
Kidney Depth (cm)	5.869	5.908	
Uptake (%)	4.461	3.642	8.103
GFR (ml/min)	40.0	32.7	72.7
Normalized GFR (ml/min)			72.1
GFR Low Normal (ml/min)			80.0
Mean GFR (ml/min)			104.0
Renal Retention			
Time of Max (min)	2.500	3.000	
Time of ½ Max (min)	15.1	14.2	
Upslope Time Interval (min)	2.500	2.250	
Max Counts (cps)	241.8	194.3	436.2
Slope from Max to ½ Max (cps²)	0.127	0.106	
Upslope (cps²)	1.453	1.614	

Time to peak

- Best from cortical ROI
- Normal < 5 min

Residual Cortical Activity (RCA20 or 30)

- Ratio of cts @ 20 or 30 min / peak cts
- Normal RCA20 for MAG3 < 0.3

Residual Urine Volume

- (post-void cts x void. vol) □ (pre-void cts - post void cts)

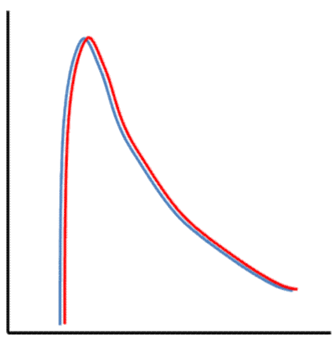
I. Vascular phase **(flow study):** **Ao-to-Kid ~ 3”**

II. Parenchymal phase **(kidney-to-bkg):** **T_{peak} < 5’**

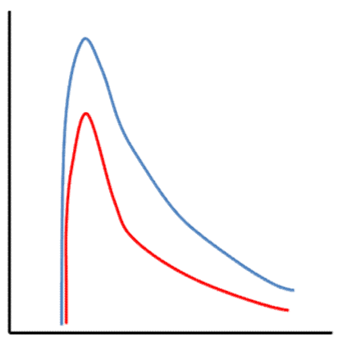
III. Washout (excretory) phase

Dynamic study

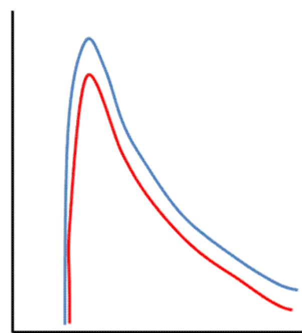
Radiorenograms



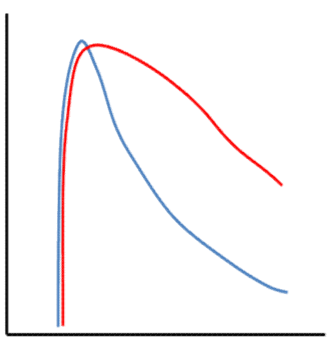
normal



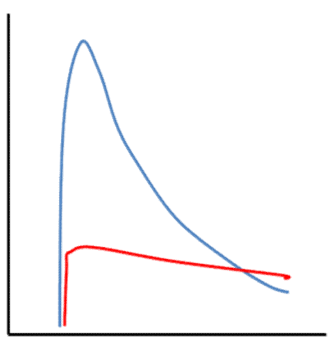
Unilateral stenosys



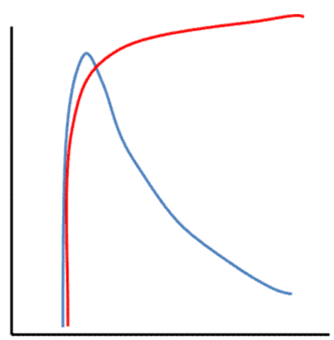
Parenchimal defent 1 kidney



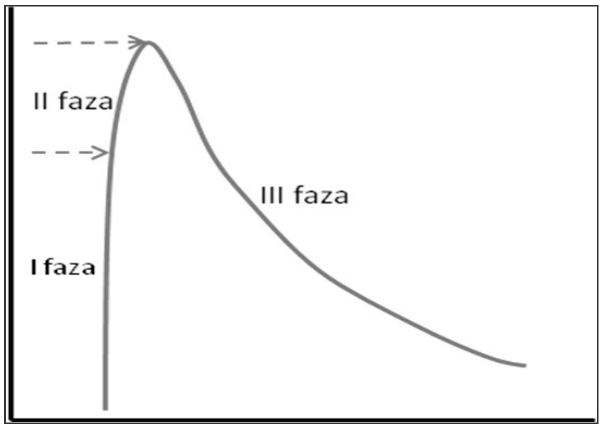
Partial obctruction



nin-functional 1 kidney



complete obsctruction



Evaluation of Hydronephrosis

Diuretic (Lasix) Renal Scan

Diuretic (Lasix) Renal Scan

Obstruction

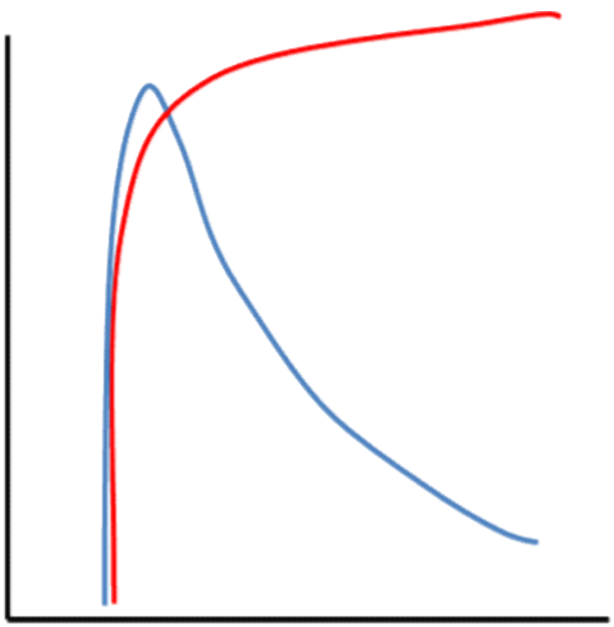
Obstruction to urine outflow leads to obstructive uropathy
(hydronephrosis, hydroureter)
and
may lead to obstructive nephropathy
(loss of renal function)

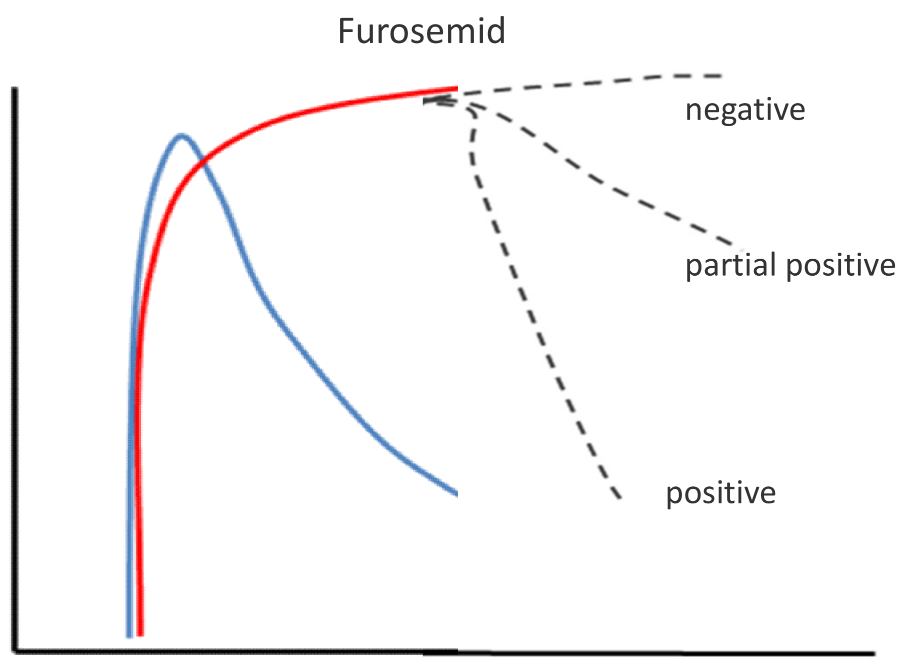
- Hydronephrosis - tracer pooling in dilated renal pelvis
- Lasix induces increased urine flow
- If obstructed >>> will not wash out
- If dilated, non-obstructed >>> will wash out
- Can quantitate rate of washout ($T_{1/2}$)

Procedure

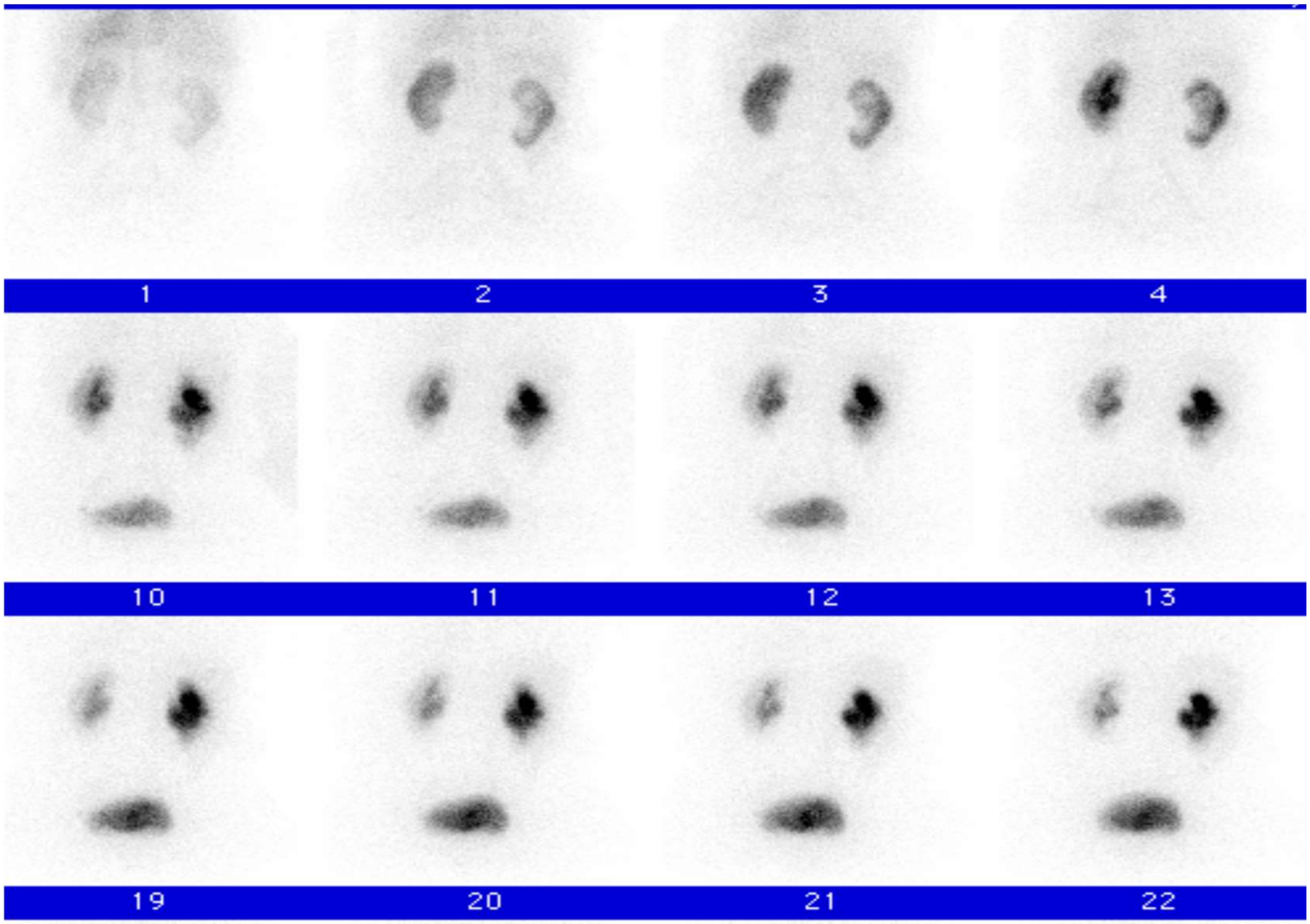
	F-15	F-0/F+2	F+20
Furosemid	❑15 Min before RF	❑ simultaniosly with RF	❑20 min after RF
Time	❑20 min	❑20 min	❑40 min
Selection	❑patients with large dilatation of the PK system ❑When the finding on the F+20 study is equivocal ❑When recording is requested in the state of maximal diuresis	❑ In children (an additional injection is avoided, children cannot lie still for 40 min) ❑Allows clarification of equivocal F+20 studies	❑ Adults only

Diuretic (Lasix) Renal Scan

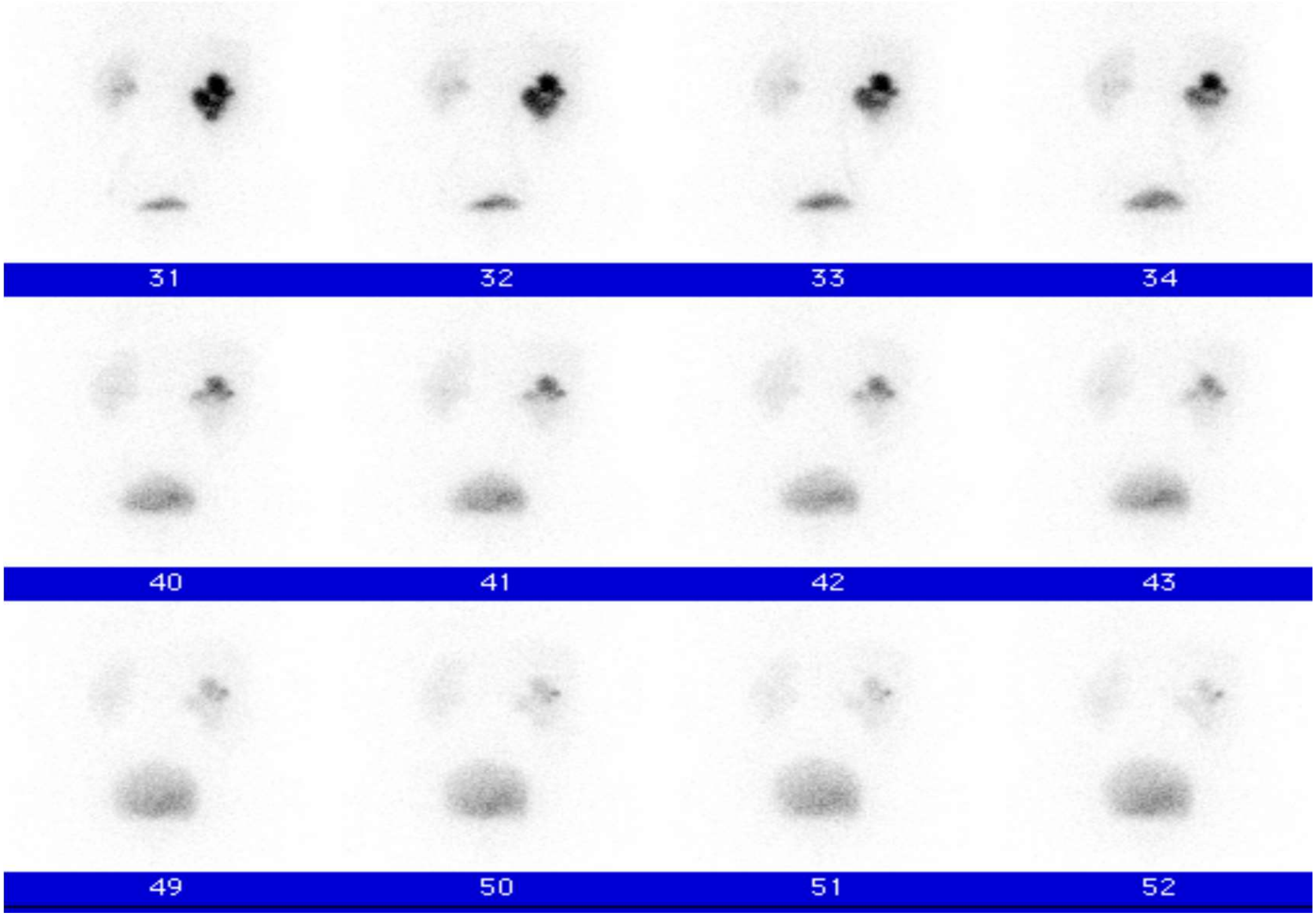




pre-Lasix



post-Lasix



Captopril Renal Scan (ACEI Renography)

Renovascular Disease

- Renal artery stenosis (RAS)
- Ischemic nephropathy
- Renovascular hypertension (RVH)

  RAS $\neq$ RVH

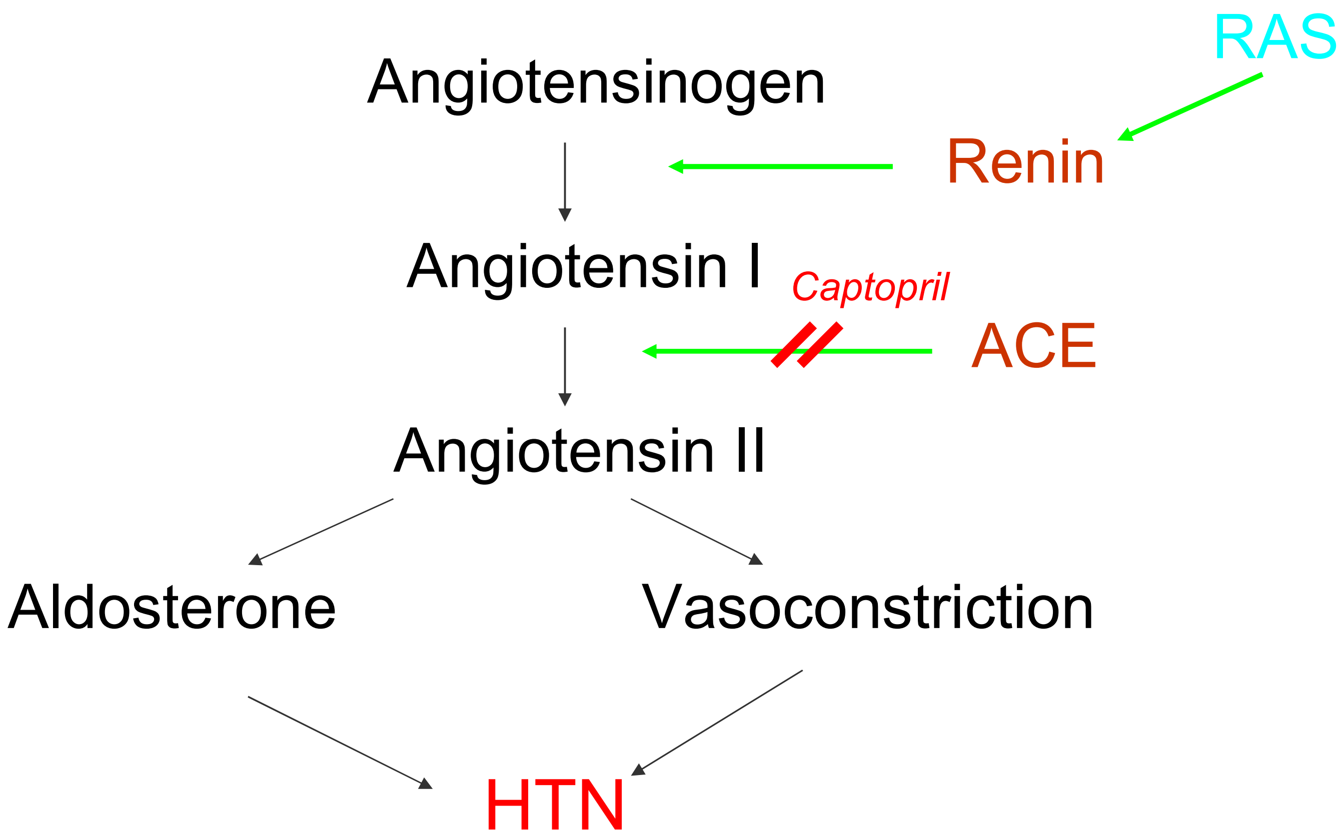
- Caused by renal hypoperfusion
  - Atherosclerosis
  - Fibromuscular dysplasia
- Mediated by renin - AT - aldosterone system
- Potentially curable by renal revascularization

Renovascular Hypertension

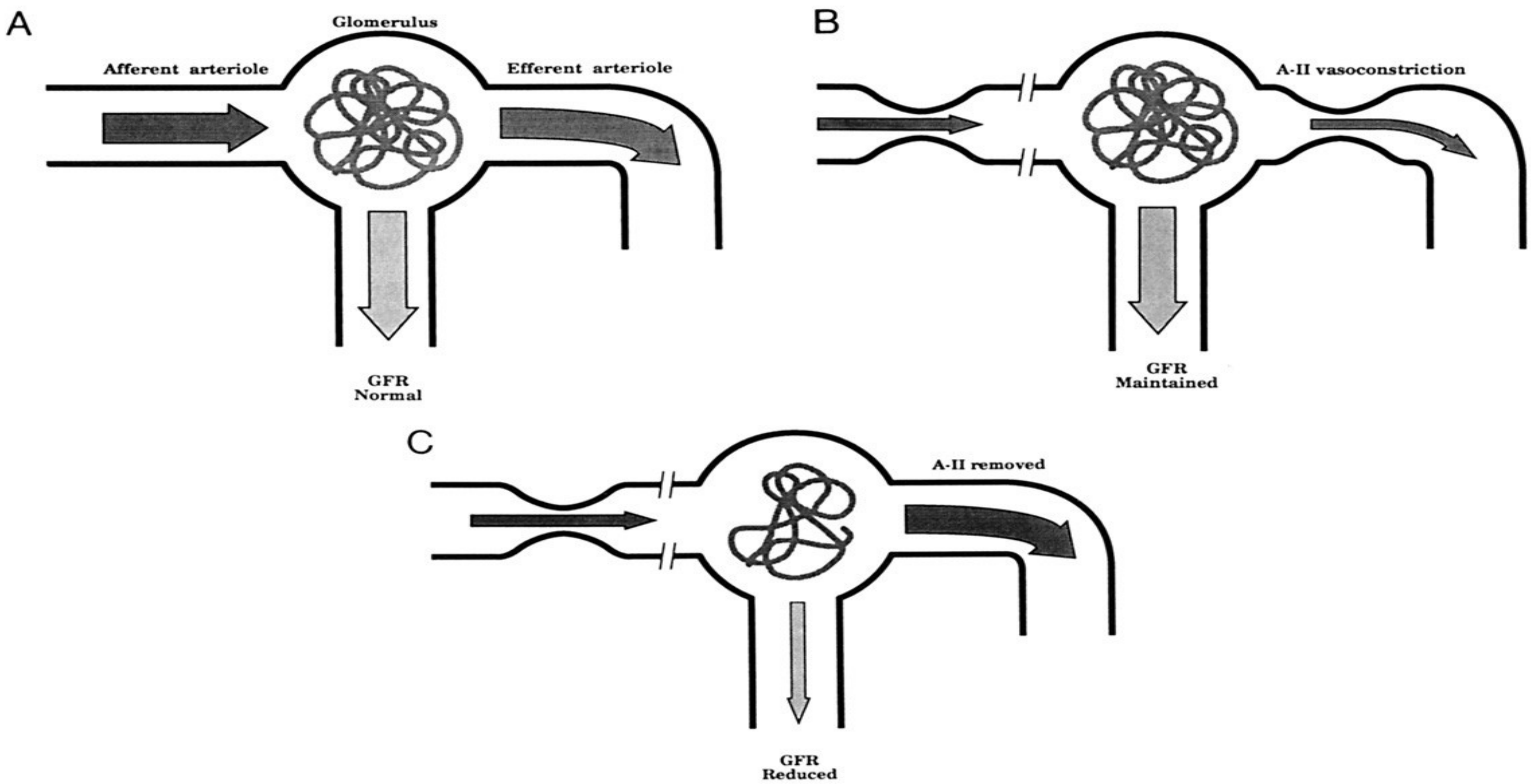
- Prevalence
  - <1% unselected population with HTN
- Clinical features
  - Abrupt onset HTN in child, adult < 30 or > 50y
  - Severe HTN resistant to medical Rx
  - Unexplained or post-ACEI impairment in ren fct
  - HTN + abdominal bruits

  If these present - moderate risk of RVH (20-30%)

Renin-Angiotensin System



Effect of RAS on GFR



Beaumont
William Beaumont Hospital

Diagnosis of RAS

- Gold std: angiography
- Initial non-invasive tests:
  - ACEI renography
  - Duplex sonography
- Other tests:
  - MRA - insensitive for distal / segmental RAS
  - Captopril test (PRA post-C.) - low sensitivity
  - Renal vein renin levels

ACEI Renography

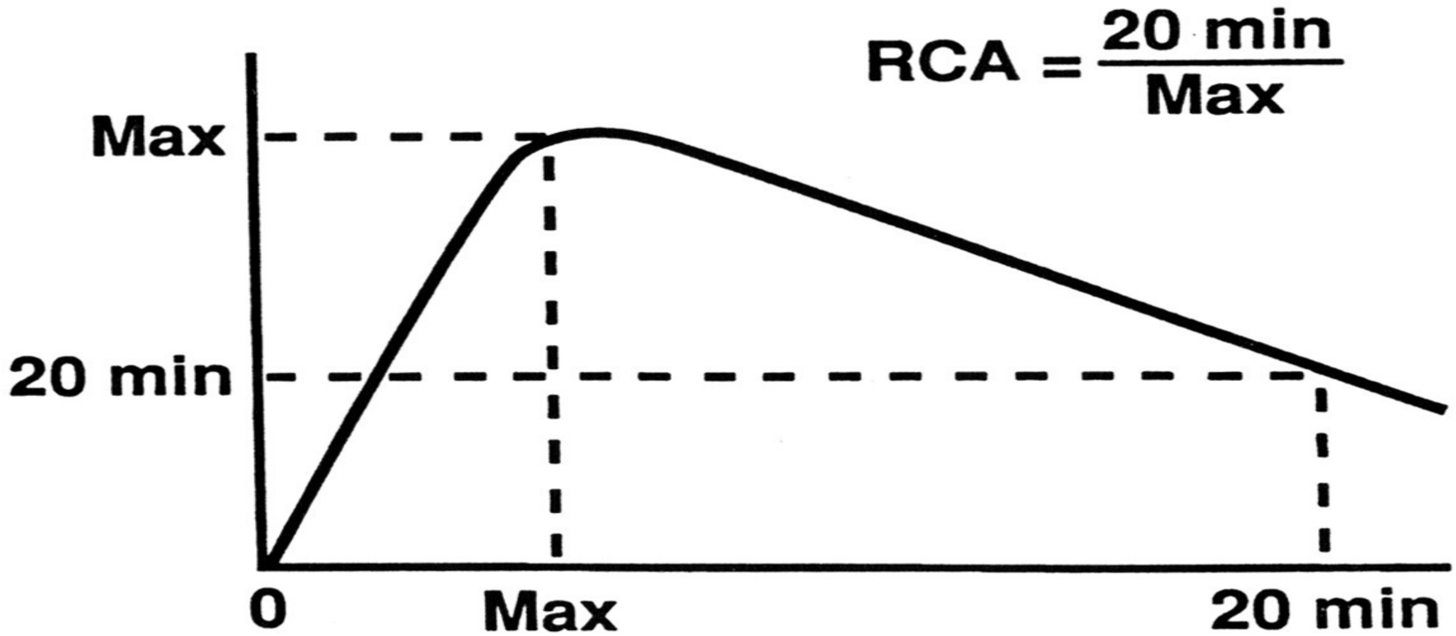
Patient Preparation

- Off ACEI & ATII receptor blockers x 3-7 days
- Off diuretics x 5-7d
- No solid food x 4 hrs
- Patient well hydrated
  - 10 ml/kg water 30-60 min pre- and during test
- ACEI
  - Captopril 25-50 mg po (crushed), 1 hr pre-scan
  - Enalaprilat 40 µg/kg iv (2.5 mg max), 15 min pre-scan
  - Monitor BP q 15 min

ACEI Renography

Procedure

- Tracer: Tc-99m MAG3 (or DTPA)
- Protocol: 1 day *vs*. 2 day test
  - 1 day test: baseline scan (1-2 mCi) followed by post-Capto scan (8-10 mCi)
  - 2 day test: post-Capto scan, only if abnormal >> baseline
- Acquisition: flow & dynamic x 20-30 min.



Relative renal uptake (bkg corrected)

Time to peak (T_p) - from cortical ROI

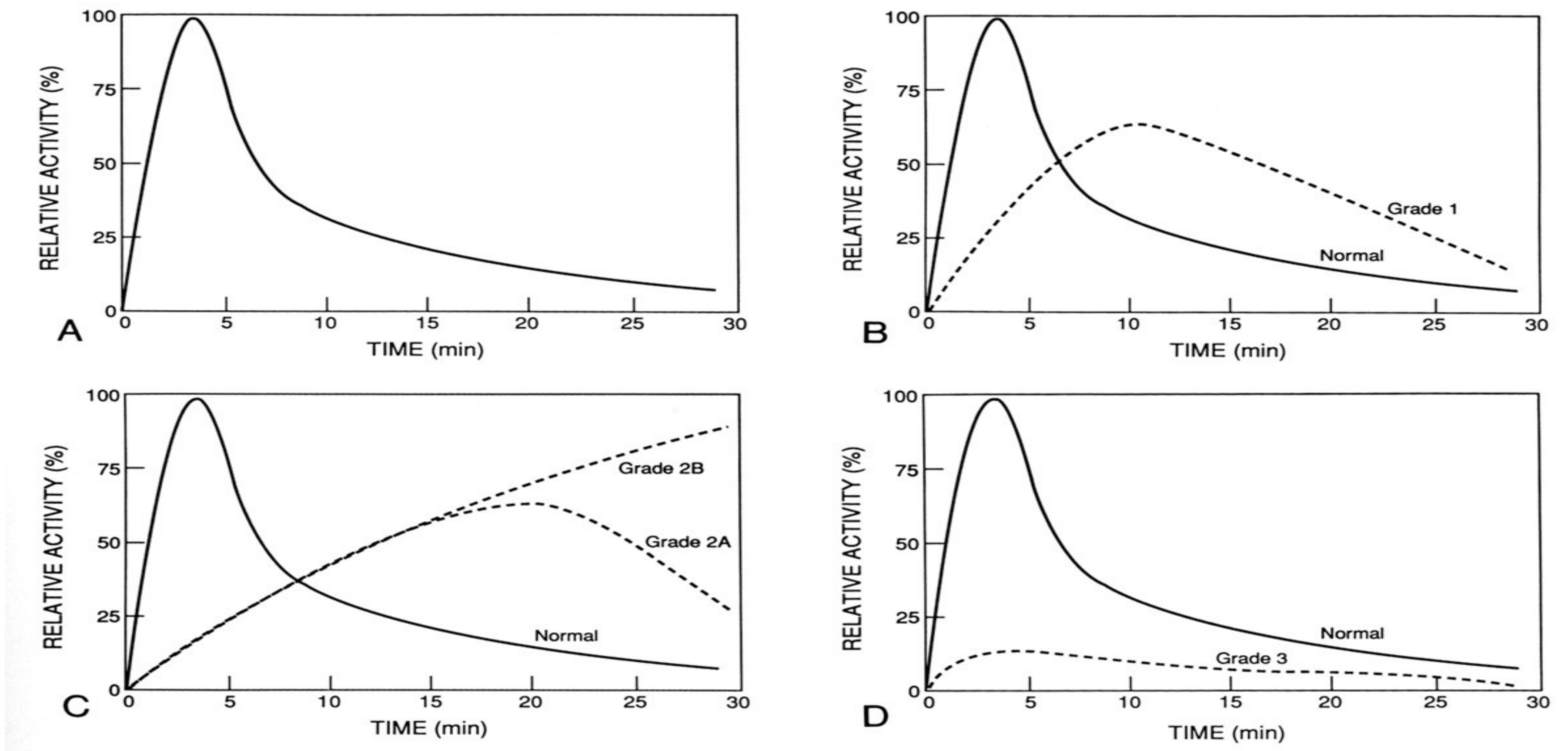
normal < 5 min

RCA_{20} (20 min/peak ratio) - from cortical ROI

normal < 0.3

ACEI Renography

Grading renogram curves

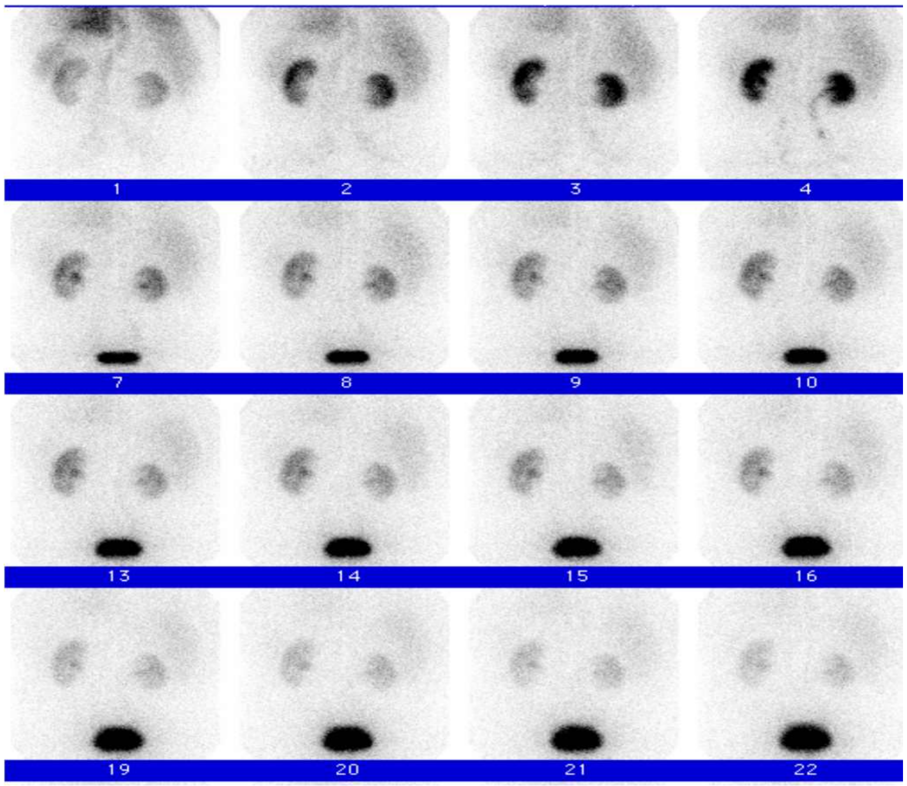


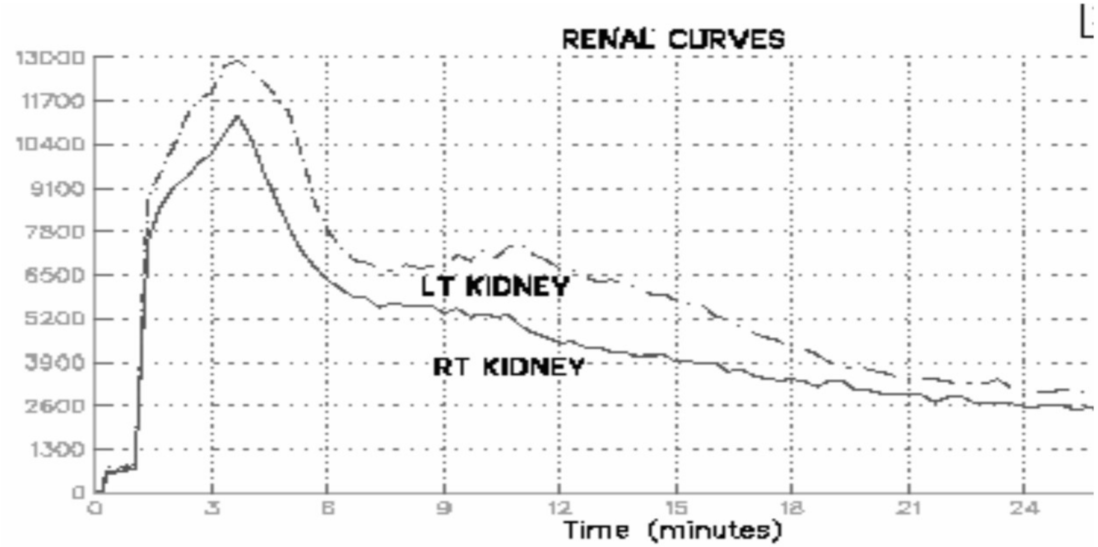
ACEI Renography

Diagnostic Criteria

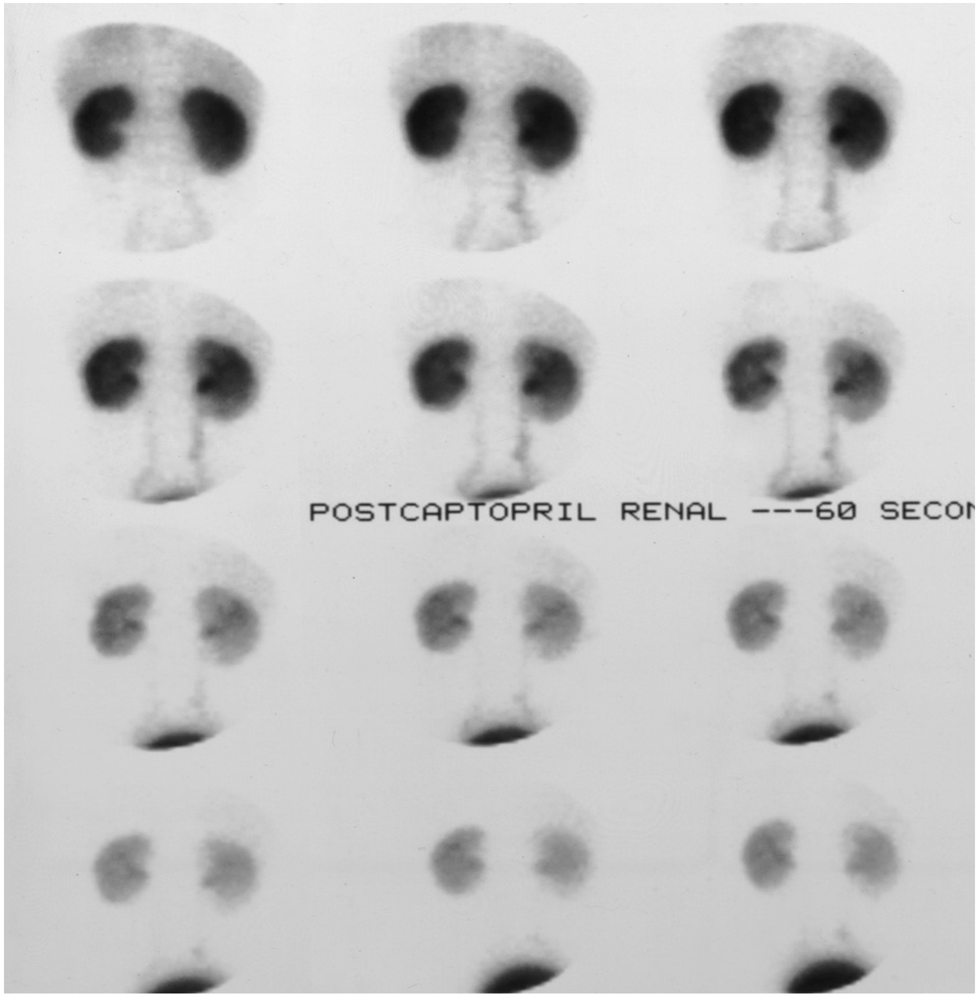
- MAG3: ipsilateral parenchymal retention p.C.
  - change in renogram curve by ≥ 1 grade
  - RCA_{20} increase by ≥ 15% (e.g. from 30% to 45%)
  - T_p increase by ≥ 2 min or 40% (e.g. from 5 to 7')
- DTPA: ipsilateral decreased uptake
  - Decrease in relative uptake ≥ 10%
    (e.g.from 50/50 to 40/60), change of 5-9% - intermediate
  - change in renogram curve by ≥ 2 grades

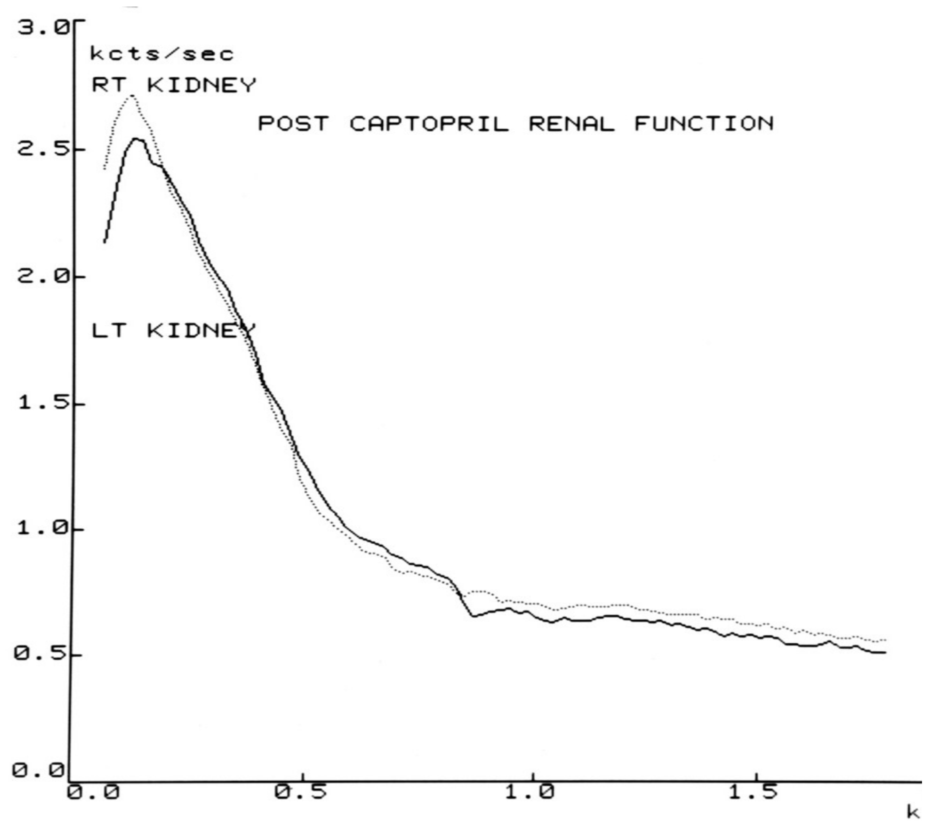
Captopril Renal Scan MAG 3





Captopril Renal Scan MAG3





Renal Morphology Scan
(Renal Cortical Scintigraphy)

Urinary tract infection (UTI)

VUR

- risk factor for PN,
- not all pts w PN have VUR

PN may lead to scarring >>> ESRD, HTN

- early Dx and Rx necessary

Clinical & laboratory Dx of renal involvement in UTI unreliable

Indications

- Determine involvement of upper tract (kidney) in acute UTI (acute pyelonephritis)
- Detect cortical scarring (chronic pyelonephr.)
- Follow-up post Rx

Renal Cortical Scintigraphy

Procedure

- Tracers
  - Tc-99m DMSA
  - Tc-99m GHA
- Acquisition
  - 2-4 hrs post-injection
  - parallel hole posterior
  - pinhole post. + post. oblique (or SPECT)
- Processing: relative fct

Renal Cortical Scintigraphy

Interpretation

Acute PN

- single or multiple “cold” defects
- renal contour not distorted
- diffuse decreased uptake
- diffusely enlarged kidney or focal bulging

Chronic PN

- volume loss, cortical thinning
- defects with sharp edges

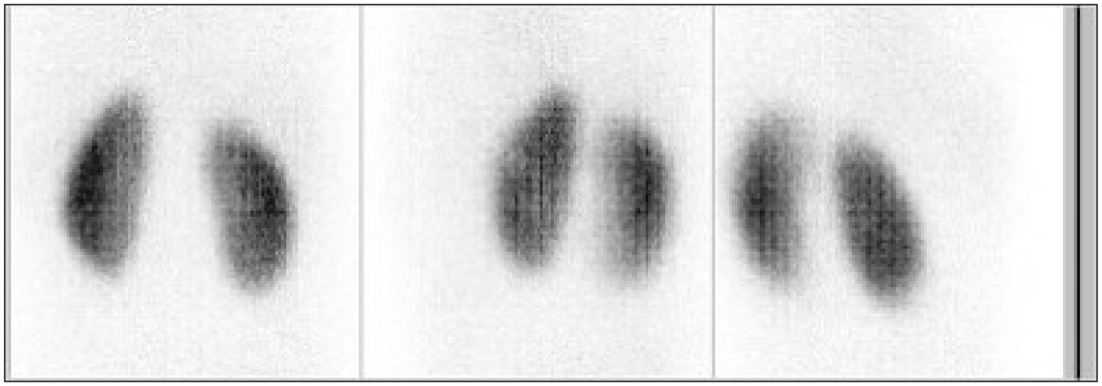
Differentiation of AcPN *vs*. ChPN unreliable

Renal Cortical Scintigraphy

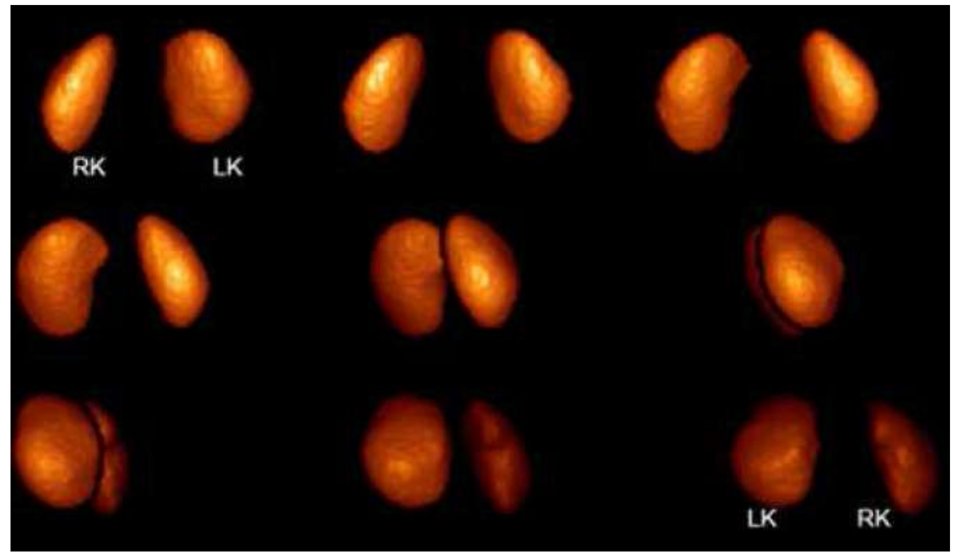
“Cold Defect“

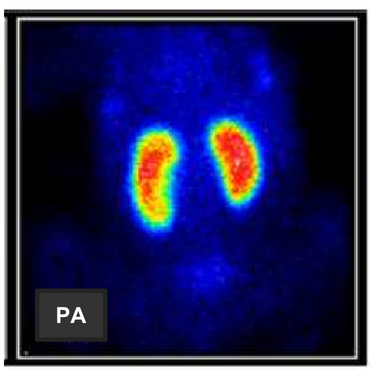
- Acute or chronic PN
- Hydronephrosis
- Cyst
- Tumors
- Trauma (contusion, laceration, rupture, hematoma)
- Infarct

Renal Cortical Scintigraphy – normal scan

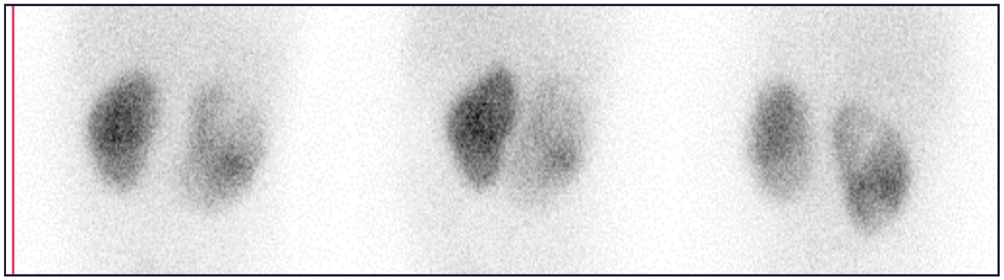


PA LPO RPO

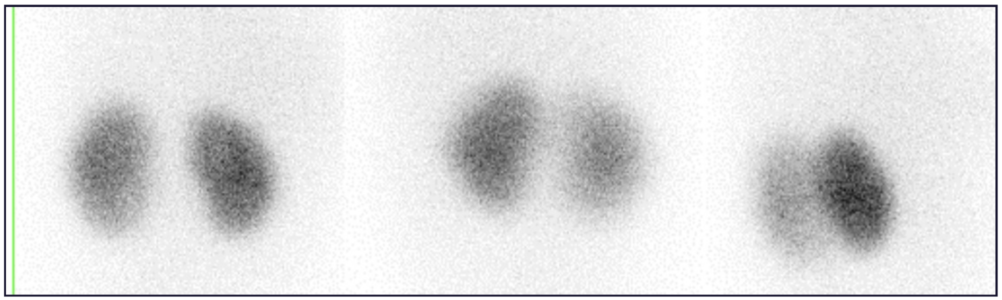




Renal Cortical Scintigraphy – acute inflamation



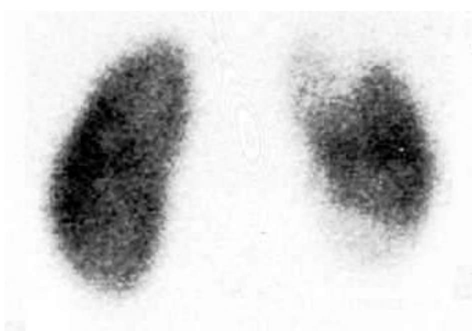
5 weeks



+6 months

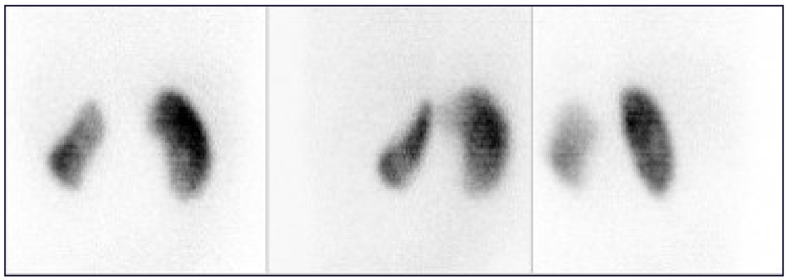
Acute pyelonephritis

3 weeks

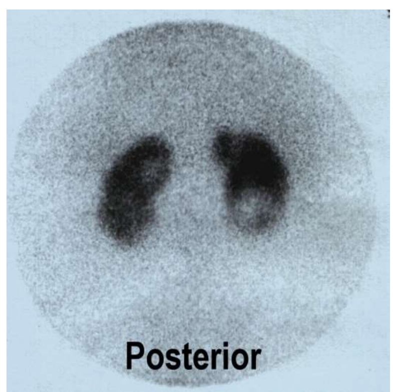


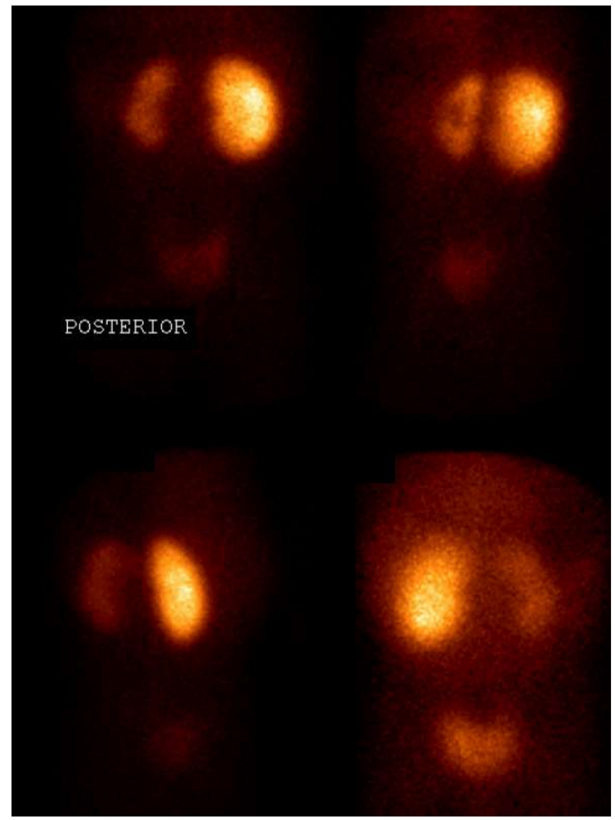
+6 months

Renal Cortical Scintigraphy – chr inflamation



PA LPO RPO



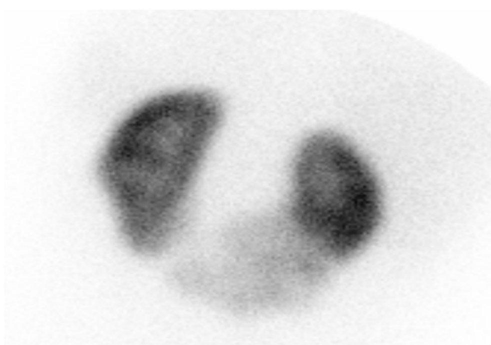


Renal Cortical Scintigraphy

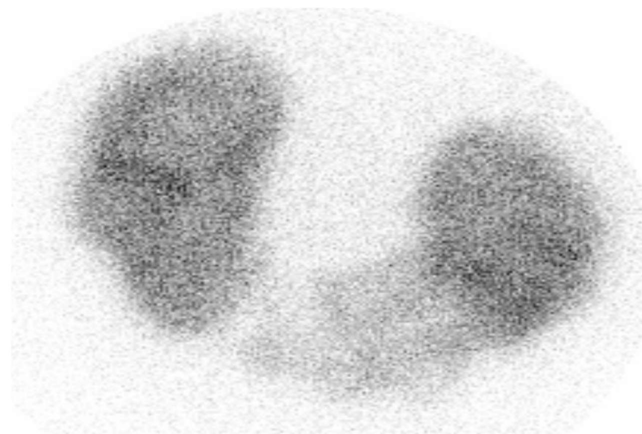
Congenital Anomalies

- Agenesis
- Ectopy
- Fusion (horseshoe, crossed fused ectopia)
- Polycystic kidney
- Multicystic dysplastic kidney
- Pseudomasses (fetal lobulation, hypertrophic column of Bertin)

DMSA
horseshoe kidney

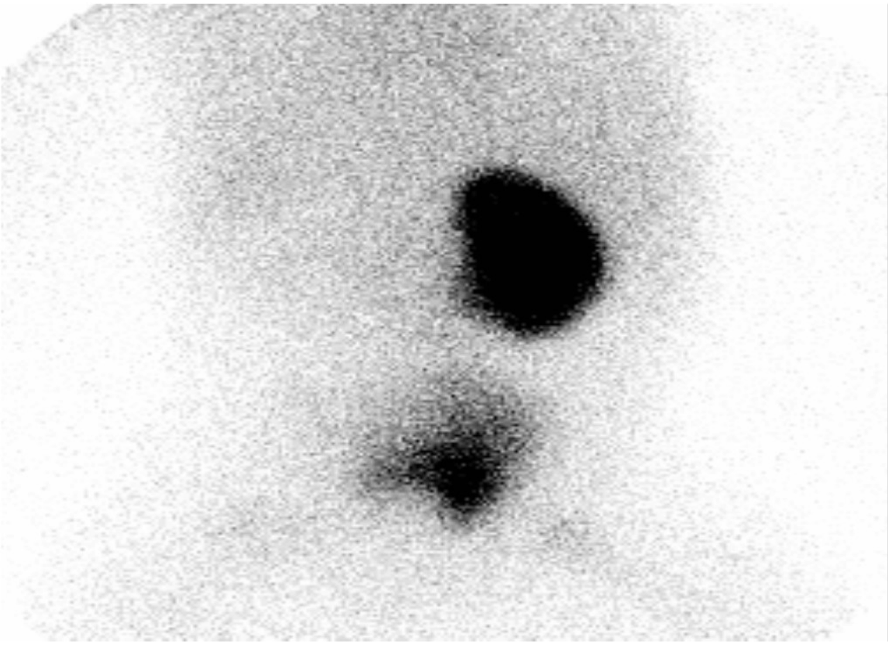


parallel



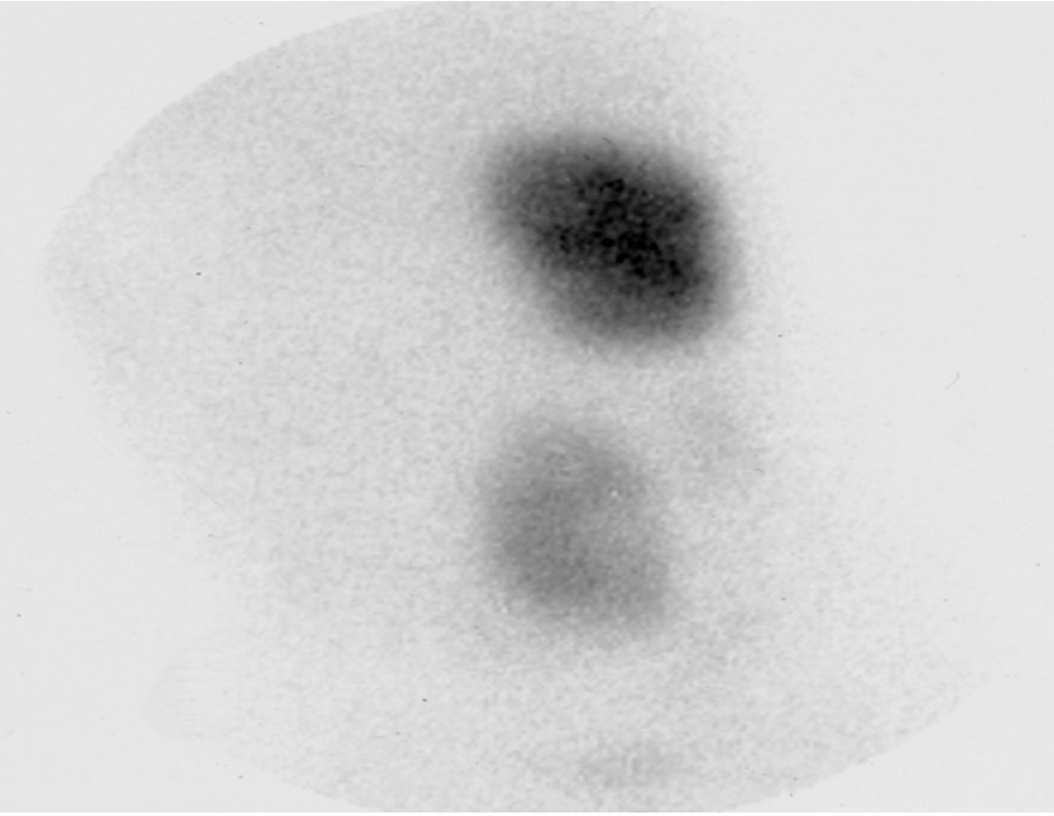
pinhole

DMSA
Lt Agenesis



parallel

DMSA Crossed ectopia



74%

26%

Radionuclide Cystogram

Indications

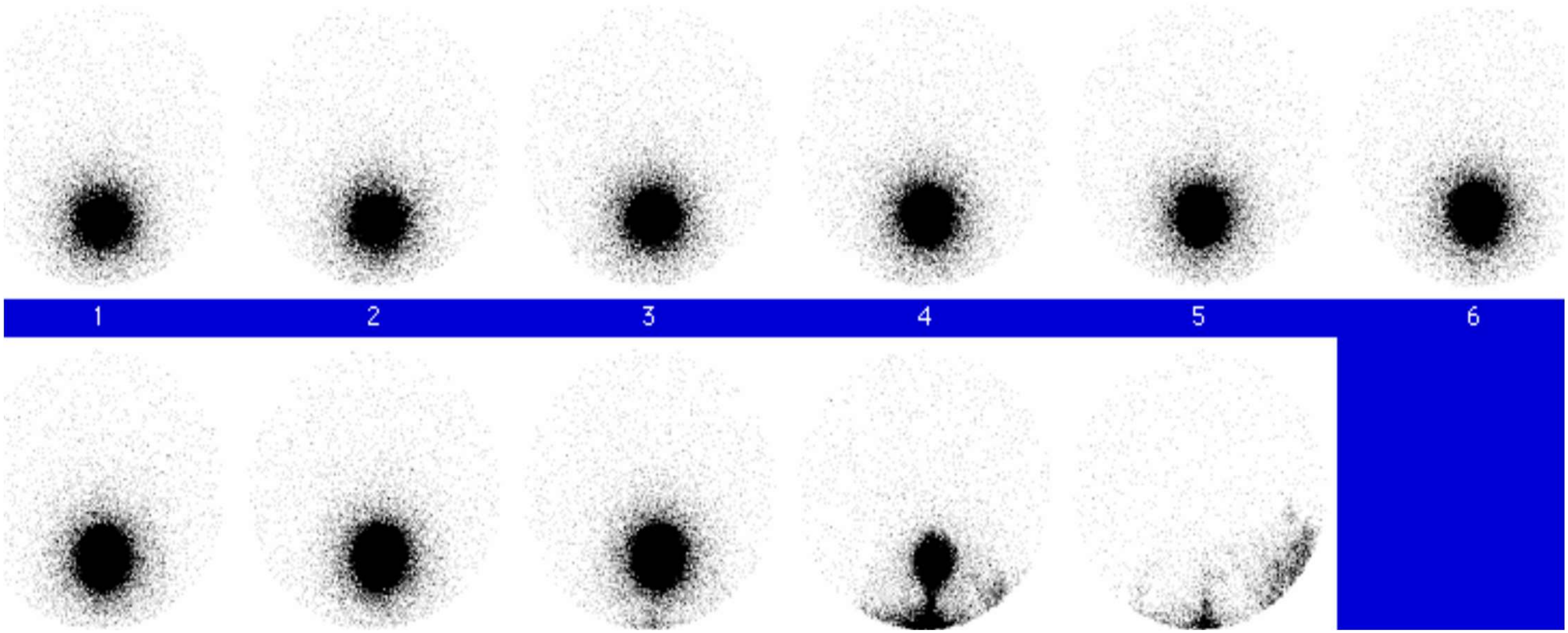
- Evaluation of children with recurrent UTI
  - 30-50% have VUR
  - VUR is the most common anomaly of the urinary tract in newborns (1%). In children with UT infections, 30-45% suffer from VUR

- F/U after initial VCUG
- Assess effect of therapy / surgery
- Screening of siblings of reflux pts.

Methods

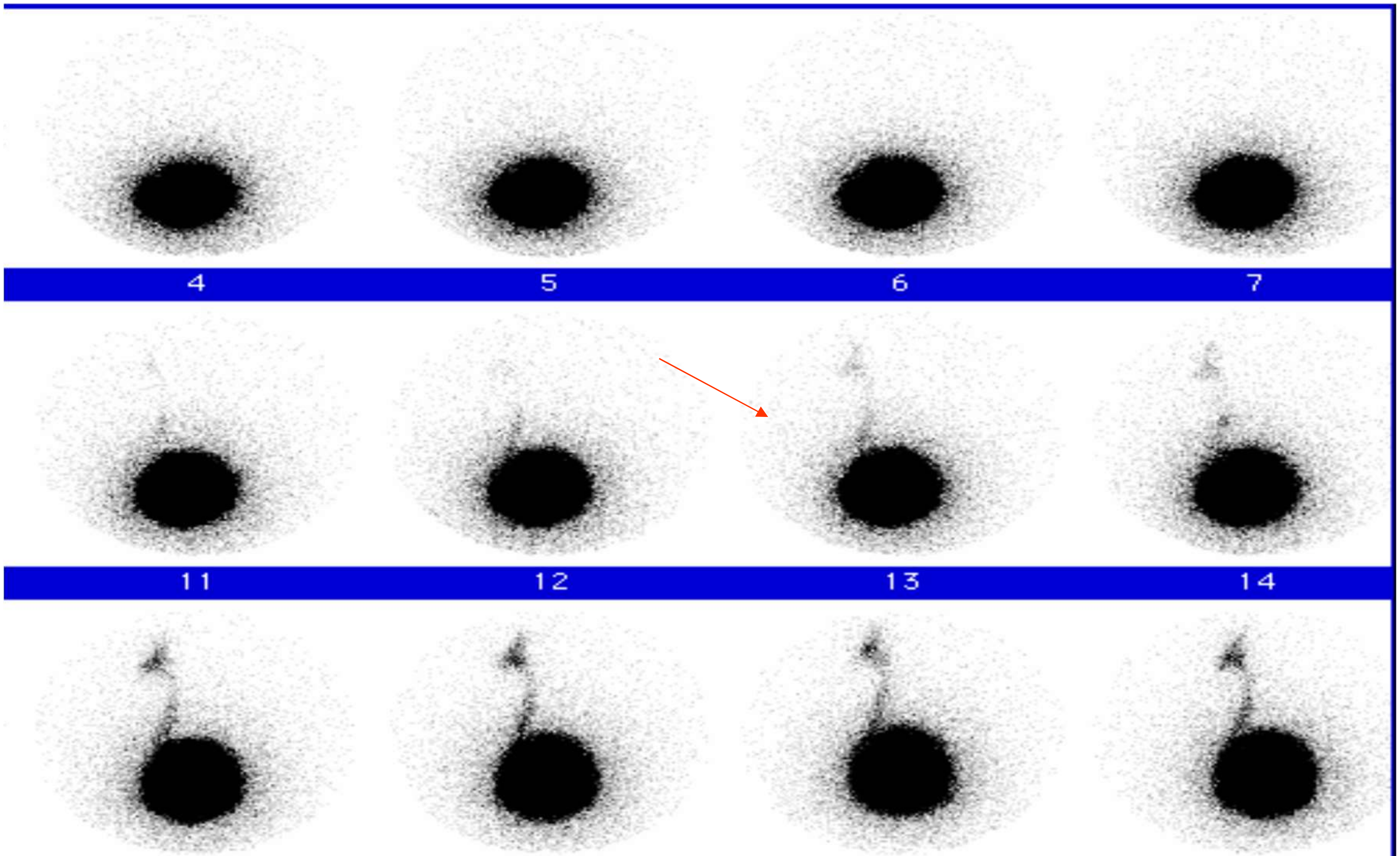
	Direct	Indirect
	• Tc-99m S.C. or TcO4	• Tc-99m DTPA or Tc-99m MAG3
	• via Foley	• i.v.
Advant.	• can do at any age • VUR during filling	• no catheter • info on kidneys
Disadv.	• catheterization	• need pt cooperation • need good renal fct

Normal cystogram

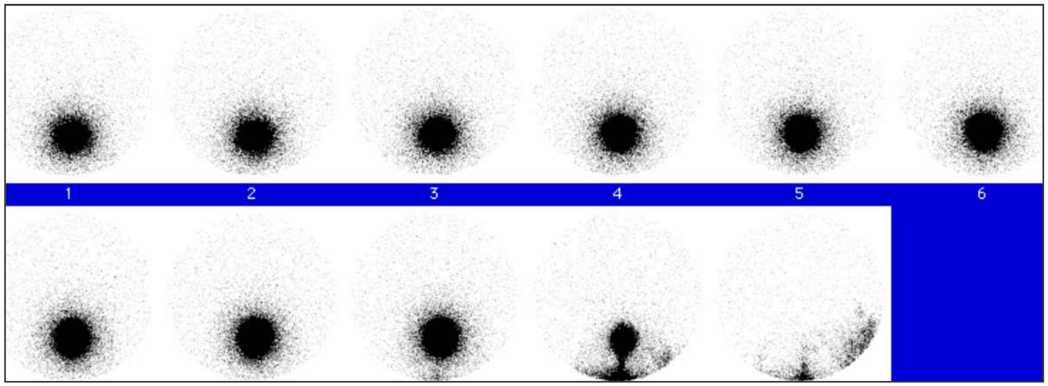


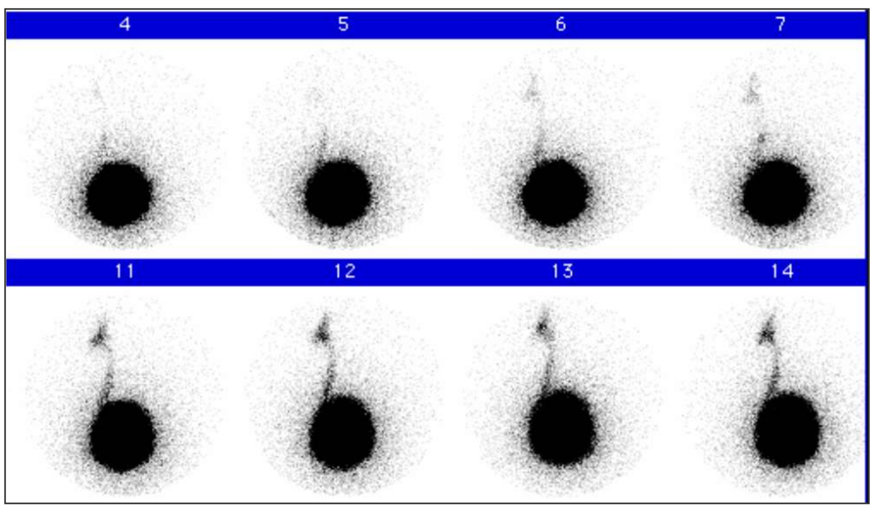
filling voiding post-void

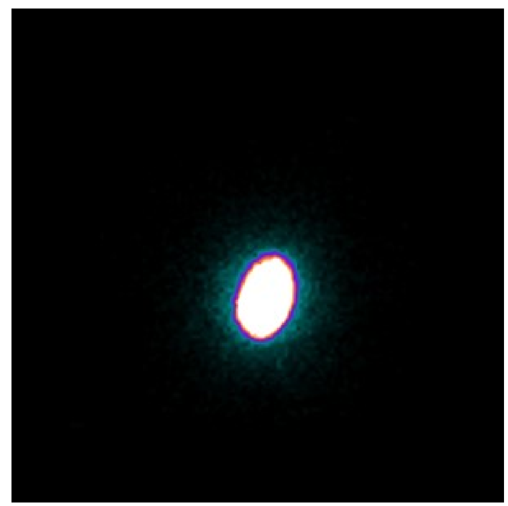
VUR - filling phase



VUR - filling phase







VUR

Post void residual volume

Prostatic hypertrophy, diabetic cystopathy can lead to bladder distension and increased risk of reflux and pyelonephritis.
Delineation of the ROI of the bladder before and after its emptying

$$RV = \frac{\text{voided vol x post-void cts}}{\text{pre-void cts - post void cts}}$$