Renal and Urographic CT Imaging

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Disclosure Statement: With a Conflict of Interest

I have/had an affiliation, financial or otherwise, with a pharmaceutical company, medical device or communications organization, which could include:

Examples:
• having received a grant(s) or an honorarium from a commercial organization.
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I intend to make therapeutic recommendations for medications that have not received regulatory approval (i.e. "off-label" use of medication).
Objective

• To review CT imaging protocols
• To demonstrate the appearances of urological anomalies and pathologies in CT imaging
• To provide background information on common urological processes
Outline

• Overview of Urinary system
• CT Protocols
• Congenital Anomalies
• Stones
• Neoplasms
• Cysts
• Vascular
• Trauma
Urinary system

- Kidneys
- Ureters
- Bladder
- Urethra
Kidneys

• The kidneys primarily filter blood coming in from the renal artery
• Cleaned blood returns to the body by the renal vein
• Waste and extra water is removed by the kidney
• Each day your kidneys filter around 200 litres of blood and produce 1 to 2 litres of waste leaving the body as urine
• The kidneys also produce renin which helps control blood pressure, erythropoietin to regulate the production of red blood cells and helps maintain strong and healthy bones
Ureters

• The ureters are approximately 12 inches long
• Thick walls composed of a fibrous, a muscular, and a mucus coat, which are able to contract
• If the passage of urine is blocked it can cause pyelonephritis, loss of renal function, or renal calculi
  • Ureteropelvic Junction obstruction (UPJ)
  • Ureterovesical Junction obstruction (UVJ)
Bladder

• One of the most elastic organs of the body
  – 600 to 800 ml of urine at maximum capacity
• The mucosal layer is lined with transitional epithelial tissue that is able to stretch to accommodate large volumes of urine
  – provides protection to the underlying tissues from acidic or alkaline urine
• The muscularis layer provides the urinary bladder with its ability to expand and contract
  – Detrusor muscle contracts during urination to expel urine from the body
Urethra

• Tube that connects the urinary bladder to the urinary meatus for the removal of fluids from the body
  – in females the urethra is about 2 inches (5cm) long
  – in males it is about 8 inches (20 cm)

• The urethra consists of three layers
  – muscular, erectile, and mucous
  – the muscular layer being a continuation of that of the bladder
Imaging Modalities

- Conventional Radiography
- Ultrasound
- Magnetic Resonance Imaging
- Nuclear Medicine
- Computed Tomography
Basics of contrast enhancement

• Non-enhanced
  – obtained for baseline attenuation measurements of renal masses, presence of calcifications, fat in lesions, stones and hemorrhagic changes

• Early arterial phase
  – 15-20 sec the contrast is still in the arteries and has not enhanced the organs

• Corticomedullary phase 30-40 seconds
  – the renal vasculature is identified which can be useful for surgical planning and renal cell carcinoma can be accurately staged
• Nephrographic phase 100-120 seconds
  – when all of the renal parenchyma including the medulla enhances
  – malignant masses can be differentiated from simple cysts as masses will enhance
  – detection of small and certain histological RCC (e.g. papillary cancer) is optimal during this phase

• Excretory phase 5-10 minutes
  – the collecting system is filled with contrast
  – assess for urothelial tumours, calyceal deformity, ureteral stricture and bladder abnormalities
CT Imaging Protocol

• Renal colic - *r/o stone*
  – N/C low dose exam, no oral contrast
  – >3mm KUB

• Renal mass - *characterize lesion, pre or post rfa*
  – N/C, CMP, NP, >3mm, +/- pelvis, same technique for all phases
  – a lesion considered enhancing if the attenuation of the increased by more 15-20 HU from baseline
• Urogram – *stage, f/u, assess UT for tcc, ureteric injury, bladder ca, neo bladder*
  – split bolus injection - combined nephrographic and excretory phase, 50 ml contrast, wait 8 minutes, then 80 ml and scan NP
  – >3mm, D> IT, turning the patient necessary to prevent layering of contrast
  – the prone position improves opacification of the distal urinary tract

• Hematuria – *hematuria NYD*
  – add renal colic prior to urogram
• Renal angio - *refractory high blood pressure*
  – Early arterial phase, D > IC, 1mm, High Quality

• Cystogram - *Urethral or bladder rupture, pelvic trauma, small bladder lesions*
  – Urinary catheter
  – Fill bladder by gravity control with 250-350 ml of diluted contrast material (50ml in 500 ml of N/S)
  – Scan IC > IT, >3mm
Congenital anomalies

- Number
- Fusion
- Location
- Shape
- Vasculature
- Collecting system
Renal agenesis

• Bilateral renal agenesis
  – classic Potter syndrome is fatal within minutes to hours

• Unilateral renal agenesis
  – accounts for about 5% of renal anomalies It usually is accompanied by ureteral agenesis with absence of the ureteral orifice
  – No treatment is necessary; the solitary kidney maintains normal renal function
Supernumerary Kidney

- Rare congenital anomaly where there are one or two accessory kidneys.
  - Less than 100 cases are documented
  - Associated anomalies are coarctation of aorta, imperforate anus and ventricular septal defects

Case courtesy of Dr Avni K P Skandhan, Radiopaedia.org
Fusion anomalies

• With fusion anomalies, the kidneys are joined, but the ureters enter the bladder on each side
  
  • Horseshoe kidney  
    – the most common fusion anomaly, occurs when renal parenchyma on each side of the vertebral column is joined at the lower poles.
  
  • Crossed fused renal ectopia  
    – is the 2nd most common fusion anomaly. The renal parenchyma (representing both kidneys) is on one side of the vertebral column. One of the ureters crosses the midline and enters the bladder on the side opposite the fused kidneys.
  
• Fused pelvic kidney (pancake kidney)  
  – is much less common. A single pelvic kidney is served by two collecting systems and ureters.
Horseshoe Kidney
Crossed fused renal ectopia
Renal ectopia

• Abnormal renal location usually results when a kidney fails to ascend from its origin in the pelvis
  – a rare exception occurs with a superiorly ascended (thoracic) kidney

• Malrotation
  – is usually of little clinical significance
Pelvic Kidney
Hypoplasia

- Underdeveloped, small kidney with histologically normal nephrons
Vasculature

• Accessory renal arteries
  – common, present in 30% of patients

• Renal vein anomalies
  – supernumerary renal veins
  – course
  – entrapment
Retroaortic renal vein
Circumaortic renal vein
Nutcracker syndrome

- Vascular compression disorder
- Refers to the compression of the left renal vein between the SMA and aorta
- Can lead to hematuria from the rupture of veins into the collecting system due to venous hypertension
Duplicated collecting system

• Duplex kidneys have a single renal unit with more than one collecting system
  – Partial - the two ureters drain into the bladder via a single common ureter
  – Complete - in which the two ureters drain separately

• Bifid renal pelvis
Partial duplicated
Bifid renal pelvis
Bladder diverticulum

• Outpouchings from the bladder wall
  – mucosa herniates through the bladder wall
• They may be solitary or multiple and can vary considerably in size
• Congenital are generally solitary
  – discovered during childhood
• Acquired are often multiple
  – typically seen in older men
  – result of bladder outlet obstruction or neurogenic bladder
STONES
Stones

• Kidney stones are quite common
  – 10% of North Americans will have a stone at least once during their lifetime
• Usually affect people aged 20 to 50 years
  – They affect men 3x more than women.
• Stones form when urine contains too much of certain crystal forming minerals
  – speck of mineral settles into the kidney, additional minerals will stick to it and develop into a stone over a period of weeks or months
Stone type

• Calcium oxalate  80% Black/Dark brown, radio-opaque
  – Calcium and oxalate in the diet can play a part in the formation.

• Calcium phosphate 5-10% Dirty white, radio-opaque
  – Tends to grow in alkaline urine (high pH).

• Uric acid 5-10% Yellow/Reddish brown, radiolucent
  – Found when urine is persistently acidic. Diets rich in animal proteins but especially in organ meats, fish, and shellfish.

• Struvite 10-15% Dirty white, radio-opaque
  – Struvite stones are related to infections in the kidney. Diet has not been shown to affect struvite stone formation.

• Cystine 1-2% Pink/Yellow, faintly radio-opaque
  – Due to cystinuria, a genetic disorder. Cystine, an amino acid is highly insoluble, precipitates out of solution and forms stones in the urine.
• Number, location, size
• Kidney
  – Obstructive vs. Non-obstructive
  – Simple vs. Staghorn
• Ureter
  – Obstructive vs. Non-obstructive
• Bladder, Urethra
Staghorn calculi

• Branched stones that occupy a large portion of the collecting system

• Typically, they fill the renal pelvis and branch into several or all of the calices
  – Frequently composed of mixtures of magnesium ammonium phosphate (struvite) and/or calcium carbonate apatite
  – Stones composed of cystine or uric acid can also grow in a staghorn configuration

• Complete removal of the stone is an important goal to relieve obstruction and preserve kidney function
Bladder stones

• Bladder stones typically begin when your bladder doesn't empty completely
  – Residual urine can form crystals that eventually become bladder stones

• The most common conditions that cause bladder stones include:
  – benign prostatic hyperplasia (BPH)
  – neurogenic bladder
  – kidney stones
Neoplasms

- Renal cell carcinoma
- Transitional cell carcinoma
- Benign solid renal mass
  - Angiomyolipoma
  - Oncocytoma
Renal cell carcinoma

• RCC is by far the most common type of kidney cancer
  – About 9 out of 10 kidney cancers are RCC
• RCC usually grows as a single tumour within 1 kidney
  – sometimes there are 2 or more tumours in one kidney or in both kidneys at the same time
• There are several subtypes of RCC
  – based mainly on how the cancer cells look under a microscope
• Knowing the subtype of RCC can be a factor in deciding treatment
  – might be due to an inherited genetic syndrome
Renal cell carcinoma

• RCC may remain clinically occult for most of its course
• 25 to 30 % of patients are asymptomatic
  – found incidentally on a radiological study
• The classic triad of flank pain, hematuria, and a palpable mass is uncommon – 10%
  – 40% will present with hematuria
  – 40% with flank pain
  – 25% with a palpable mass in the abdomen
• The incidence of RCC has been rising steadily in Europe and the United States for the past 3 decades
  – 6000 new cases 3800 males, 2300 females in Canada
  – 61500 new cases, 14000 deaths in U.S.
• Higher rates are reported for men than women (1.5:1)
• The average age at diagnosis of CCRCC is 60-64 years
• Approximately 30% of patients with RCC present with metastatic disease
  – Lung (75%)
  – Bone (20%)
  – Liver (18%)
  – Central nervous system (8%)
RCC histologic subtypes

• Clear cell - most common (75%)
  – originates from the renal cortex and typically exhibits an expansile growth pattern
  – appears heterogeneous at imaging due to the presence of hemorrhage, necrosis, and cysts

• Papillary - finger like projections (chromophilic) (15%)
  – commonly affects end-stage kidneys
  – bilateral and multifocal tumors are more common than in other subtypes
  – typically appear hypovascular and homogeneous on imaging studies

• Chromophobic (5%)
  – typically appear in the 6th decade, men and women are equally affected
  – overall good prognosis, but large tumors may result in hepatic metastases
Rare types-(1%)

• Collecting duct - very aggressive, highly metastatic
• Multilocular cystic RCC- excellent prognosis, recurrence and metastasis have not been reported
• Medullary carcinoma- occurs in patients with sickle cell trait
  – found in young patients; age range is between 10 and 40 years, 2:1 male-to-female ratio
  – poor prognosis with a mean duration of survival of 15 weeks
• Mucinous tubular and spindle cell carcinoma- predominantly affects women; considered nonaggressive with a favorable prognosis
• Neuroblastoma-associated RCC- unique subtype that occurs in long-term survivors of pediatric neuroblastoma
  – occurs several years after the diagnosis of neuroblastoma is believed that the treatment for neuroblastoma may be responsible for RCC.
• Unclassified lesions (4%)
Transitional cell carcinoma

- Urothelial cell carcinoma
- The renal pelvis and ureters are lined with transitional cells
- TCC accounts for 90% of all cancers arising from the renal pelvic urothelium
  - Less than 10% of kidney cancers
- TCC is frequently multifocal and may involve any part of the collecting system
• Only 4% of patients with bladder cancer develop upper tract TCC, but 40% of patients with upper tract TCC develop bladder cancer

• TCC are typically of soft tissue density
  – enhance significantly less than renal parenchyma

• Usually centred on the renal pelvis and range in size from small filling defects to large masses which obliterate the renal sinus fat
Bladder Ca

• TCC is the most common primary neoplasm of the urinary bladder (90%)
  – bladder TCC is the most common cancer of the urinary system
• Hematuria is the most common presentation
  – ureteral obstruction and hydronephrosis
  – bladder outlet obstruction and urinary retention
• Squamous cell carcinoma of the bladder accounts for only 3-8%
  – common in the setting of chronic irritation, such as that seen from bladder stones
Bladder TCC appear as:

- Focal regions of thickening of the bladder wall
- Masses protruding into the bladder lumen
- Extending into adjacent tissues in advanced cases
Angiomyolipoma (AML)

• Benign renal neoplasm that is composed of vascular (angio), smooth muscle (myo) and fat (lipoma) elements
• Most lesions involve the cortex and demonstrate macroscopic fat (less than -20 HU)
• Asymptomatic but can spontaneously hemorrhage
• > 4 cm is at risk for a retroperitoneal hemorrhage and shock
Angiomyolipoma
Oncocytoma

• Benign renal neoplasm
  – asymptomatic, often large at presentation

• The imaging characteristics of oncocytomas and RCCs overlap
  – differentiating from an RCC and is not always possible

• Helpful sign is the presence of a sharp central stellate scar
  – only seen in a third of cases
CYSTS
Cysts

- Cystic kidney disease refers to a wide range of hereditary, developmental, and acquired conditions
  - may involve one or both kidneys
  - may or may not occur in the presence of other anomalies
  - higher incidence of cystic kidney disease is found in the male population and prevalence increases with age
Simple Cysts

• Renal cysts occur in more than 50% of patients over the age of 50
• Sharp demarcation with a smooth thin wall
• Homogeneous fluid within the cyst
• No contrast enhancement
• Benign renal cysts do show progressive slow expansion
Bosniak classification system of renal cystic masses

- Divides renal cystic masses into 5 categories based on imaging characteristics on CECT
- Helpful in predicting risk of malignancy and suggesting f/u or treatment
Bosniak 1

- Simple cyst
- Rounded, imperceptible wall
- No work up
- 0% malignant
Bosniak 2

- Minimally complex
- A few thin septa
- Thin calcifications
- Non-enhancing high attenuation lesions of less than 3 cm
- No work up
- 0% malignant
Bosniak 2F

- Minimally complex but requires f/u
- Increased number of septa, minimally thickened or enhancing
- Thick calcifications
- Hyperdense cyst >3 cm, mostly intrarenal
- No enhancement
- Workup: needs US/CT
- 25% malignant
Bosniak 3

- Indeterminate
- Thick or multiple septations
- Mural nodule
- Hyperdense on CT
- Workup/ TX partial nephrectomy or RFA
- 54% malignant
Bosniak 4

- Clearly malignant
- Solid mass with large cystic or necrotic component
- TX partial of total nephrectomy
- 100% malignant
Polycystic kidney disease (PKD)

- Is a genetic disorder characterized by the growth of numerous cysts in the kidneys which can number in the thousands
- PKD cysts can profoundly enlarge the kidneys while replacing much of the normal structure, resulting in reduced kidney function and leading to kidney failure
- In fully developed autosomal dominant PKD, a cyst-filled kidney can weigh as much as 20 to 30 pounds
Two major inherited forms of PKD exist:

- **Autosomal dominant PKD**
  - is the most common inherited form (90%)
  - Symptoms usually develop between the ages of 30 and 40
  - often called "adult polycystic kidney disease"

- **Autosomal recessive PKD**
  - is a rare inherited form
  - Symptoms frequently begin before birth or in the earliest months of life
  - often called "infantile PKD"
• About one-half of people with autosomal dominant PKD progress to end-stage renal disease (ESRD)

• PKD can also cause:
  – Cysts in the liver and pancreas
  – Cardiac valve disease (25%)
  – Cerebral aneurysms (5-10%)
  – Diverticulosis
VASCULAR
Vascular

• Reno vascular diseases primarily affect the renal arteries and result in hypertension and kidney dysfunction
  – Atherosclerotic renal artery stenosis 90%
  – Fibromuscular dysplasia (FMD) 10% of RAS

• FMD affects the linings of the renal artery
  – characteristic beaded appearance on renal angiograms
  – more common in women and individuals between the ages of 25 and 50
  – rarely leads to total renal artery blockage
Renal infarction

• One or more wedge-shaped parenchymal defects
  – involve both the cortex and medulla
• If the main renal artery is occluded, then the entire kidney fails to enhance
  – thromboembolic event of cardiac origin
  – aortic or renal artery dissection
  – fibromuscular dysplasia (FMD)
  – renal trauma
TRAUMA
Renal Trauma

• The kidney is injured in up to 10% of patients who sustain significant abdominal trauma
• Most renal injuries (90%) result from blunt trauma
  – most injuries are low grade
• Renal trauma grading is often done using the American Association for the Surgery of Trauma (AAST) scale
  – depth of damage and involvement of the collecting system and renal vessels
Grade I

- contusion or non enlarging subcapsular hematoma
- no laceration
Grade II

- superficial laceration <1cm depth and does not involve the collecting system
- non expanding perirenal hematoma
Grade III

- laceration >1cm, without extension into the renal pelvis or collecting system
- no evidence of urine extravasation
Grade IV

- Laceration extends to renal pelvis or urinary extravasation
- Vascular injury to main renal artery or vein with contained hemorrhage
Grade V

- shattered kidney
- avulsion of renal hilum: devascularisation of kidney due to hilar injury
Bladder Trauma

• Bladder injuries can result from blunt or penetrating trauma
• Blunt trauma 60%-85%
  – MVC, fall, assault
• Penetrating trauma 15%-40%
  – GSW, stabbing
• Ruptures are classified as extraperitoneal, intraperitoneal or combined
• Extraperitoneal 50%-71%
• Usually associated with pelvic fracture
• The classic cystographic finding is contrast extravasation around the base of the bladder, confined to the perivesical space.
• Extravasation will reach the scrotum when the urogenital diaphragm becomes disrupted
• Intraperitoneal 25%-43%
• Tear in the bladder dome
  – least supported area of the bladder
• Sudden large increase in pressure that overcomes the mechanical strength of the bladder wall
• Contrast extravasation into the peritoneal cavity
  – outline loops of bowel, fill the paracolic gutters, and pool under the diaphragm
• Combined extra and intraperitoneal 7%-14%
• Simultaneous intraperitoneal and extraperitoneal injury
• Demonstrates extravasation patterns that are typical for both types of injury
• Mortality rates in approach 60%
• Often observed in penetrating trauma
  – This through-and-through injury creates a combined intraperitoneal and extraperitoneal bladder rupture
Summary

• Reviewed common anomalies and pathologies demonstrated in CT
• CT is a great diagnostic tool that can be used alone or in conjunction with other modalities to evaluate the urinary tract for a variety of indications
• Special care should be taken to ensure CT protocols are optimized to ensure the exam is diagnostic
Thank you