Introduction to Urinary Tract

This lecture introduces the common radiologic techniques used in evaluation of the urinary tract. Emphasis is on a detailed description of each technique as it applies to the urinary tract. Also, a discussion of normal anatomy and some important fundamental concepts of interpretation is included.
Conventional radiographs (plain films) can occasionally provide important clues to diseases of the urinary tract. Radiographs of the abdomen when used to evaluate the urinary tract are often referred to as KUBs (kidney, ureter, and bladder). KUBs may serve a role as preliminary films (scouts) prior to an examination such as an intravenous urography, or they may be used as a general evaluation of the abdomen or the urinary tract. Abnormalities of the urinary tract may be suggested on conventional radiographs and, among other things, the bones and soft tissues should be evaluated and abnormal densities, especially calcifications, should be sought. "Gas, mass, bones, stones" can be used as a reminder of main areas to examine on the KUB. Soft tissue masses can occasionally be detected and suggest renal or pelvic lesions. Sclerotic bony lesions can suggest metastatic prostate cancer and lytic bony lesions can be seen with disseminated renal cell carcinoma. Additionally, the bony changes of renal osteodystrophy (diffuse bony sclerosis) may be identified on plain radiographs. Vertebral anomalies are associated with congenital malformations of the urinary tract.
Radiographs are useful for detecting and evaluating urinary tract calculi. It has been reported that 90% of calculi are radiopaque and can be identified on conventional radiographs. However, recent studies suggest that no more than 40% to 60% of urinary tract stones are detected and accurately diagnosed on plain radiographs. The sensitivity for detection of stones is limited when the calculi are small, of lower density composition, or when overlapping stool, bony structures, or air is obscuring the stones. Additionally, the specificity of conventional radiography is somewhat limited because a multitude of other calcifications occur in the abdomen, including arterial vascular calcifications, pancreatic calcifications, gallstones, leiomyomas, and many more. (More than 200 causes of calcification in the abdomen have been described.) Phleboliths, which are calcified venous thromboses, are especially problematic because they frequently overlap the urinary tract and are difficult to differentiate from distal ureteral stones. Lucent centers are a hallmark of phleboliths, whereas renal calculi are often most dense centrally. Additionally, oblique films and tomograms may be useful to differentiate true renal calculi from densities within the tissues anterior or posterior to the kidney.
In the setting of trauma, fractures of the lumbar transverse processes suggest possible renal injuries and pelvic fractures raise concern for coexistent bladder or urethral trauma. Air and calcifications should be specifically sought over the urinary tract. Emphysematous pyelonephritis, a urologic emergency with high mortality, is the result of a renal infection by gas-producing organisms and may be diagnosed on plain films by mottled or linear collections of air within the renal parenchyma. If emphysematous pyelonephritis is suspected, emergency computed tomography (CT) should be performed to delineate the.
Intravenous urography (IVU), also known as intravenous pyelography (or more commonly, the IVP), has dominated imaging of the urinary tract for more than 50 years. Although recent advances in other techniques have substantially reduced its role, IVU remains an important study for some urinary tract disease processes. More importantly, however, decades of use of the IVU have established the fundamentals of imaging evaluation of the urinary tract. An understanding of these principles forms a foundation for radiologic interpretation of the urinary tract with the IVU or other more "advanced" imaging modalities. Thus, the IVU technique is explained with interspersed discussion of anatomy, normal variants, and, most importantly, some fundamentals of interpretation. Although an urgent examination should not be delayed to prepare a patient for an IVU, overlying stool can obscure important detail on an intravenous urogram and therefore a mild bowel preparation of clear liquids and laxatives before an elective study is recommended. The study should always begin with a scout KUB. This has several purposes including detection of calcifications (which may be obscured after contrast material is injected), assurance of proper technique (patient positioning, exposure parameters) prior to contrast administration, and exclusion of contraindications to the study (retained barium, etc.).
Intravenously injected iodinated contrast is excreted primarily by glomerular filtration in the kidney, opacifying the urinary tract as it progresses from the kidney through the ureter and to the bladder. Within 1 to 3 minutes after injection, the contrast bolus is filtered by the glomeruli and fills the nephron, resulting in intense opacification of the renal parenchyma; this phase of contrast opacification is called the nephrogram. Evaluation of the kidneys during the nephrographic phase is often enhanced with tomograms (nephrotomograms).
The kidneys should be evaluated for their position, orientation, size, contour, and radiographic density.
The size of the kidneys is somewhat variable depending on age and sex of the patient, but on the intravenous urogram the kidneys normally range from 11 to 14 cm. The right kidney is typically slightly smaller than the left. Measurement of renal size is also dependent on the examination. For example, on the IVU the kidneys appear artificially larger due to magnification. To account for this as well as other parameters such as overall body size, a generalization is that the kidneys should measure between three and four lumbar vertebra lengths. Additionally, the kidneys should be symmetric in size with a discrepancy greater than 2 cm requiring an explanation. There are a number of causes of abnormal renal size, ranging from incidental anomalies such as congenital renal hypoplasia to significant conditions such as renal artery stenosis (small kidney) or infiltrating renal neoplasm (large kidney). The kidneys should have a reniform shape and a smooth contour.
The kidneys are typically located at the level of the upper lumbar spine with the right kidney slightly lower than the left. They generally lie with their axes along the psoas muscles with the upper pole slightly more medial than the lower. Alterations in position and orientation of the kidneys may be related to congenital anomalies such as pelvic kidneys or may be secondary to mass effect from an adjacent lesion.
A key concept in evaluation of a possible mass is parenchymal thickness as measured from calyces to edge of the kidney.
The radiographic density of the kidneys following contrast injection is related to arterial supply, renal function and excretion, and venous outflow. Alterations in any of these parameters may result in abnormalities of one or both of the nephrograms. For example, ureteral obstruction results in a delayed and increasingly dense nephrogram.
The intrarenal collecting system consists of calyces, infundibula, and the renal pelvis. The renal pelvis should be evaluated for filling defects and mass effect.
Intravenous Urography

- Position
- Size
- Shape
- Parenchyma
- Renal function and excretion
- Calyces, infundibula, and the renal pelvis
- Ureter
- Bladder

The ureter extends from the ureteral pelvic junction to the ureteral vesicle junction. Proximally, the ureter passes over the psoas muscle and should generally lay just lateral to the lumbar spine. The midportions of the ureters course over the lateral sacrum with the distal portion gently curving laterally in the pelvis before entering the bladder. The ureter is an actively peristalsing structure that is not normally seen in total on the IVU. In fact, complete visualization of the ureter may suggest distal obstruction. The ureter should be inspected for filling defects, which can be caused by stones or tumor, and should be symmetric in size. Evaluation of the ureteral course is important. Typically, the ureter should be no more lateral than the tips of the lumbar transverse processes and no more medial than the lumbar pedicles. Deviations of the normal ureter generally suggest extrinsic diseases, such as mass lesions. However, in patients with large psoas muscles the ureters may be displaced laterally as an incidental result.
Finally, the bladder is opacified last on the study beginning around 5 minutes after injection. The bladder is an oval to rounded structure that normally lies just above the pubic symphysis on the IVU. In women, the dome of the bladder may normally be indented by the uterus. These normal findings must be differentiated from abnormal extrinsic mass effects. Bladder wall thickness can sometimes be visualized and assessed, especially if thickened. Additionally, the bladder mucosa should be scrutinized for irregularity or filling defects that may suggest a mass.
Direct injection of water-soluble iodinated contrast material is a useful method of examining various regions of the urinary tract. The advantage of this method of evaluation is the direct control over the contrast injection rather than reliance on secondary excretion from the kidney. Retrograde pyelography, often carried out in conjunction with cystoscopy, is performed by placing a small catheter into the distal ureter. Contrast material is then injected through this catheter into one or both ureters. Fluoroscopy and conventional radiographs should then be obtained. This study usually results in excellent evaluation of the ureter and intrarenal collecting system. The ureter is typically seen in its entirety, which rarely occurs with other imaging studies. Interpretation is similar to that of the IVU with the caveat that the contrast within the collecting system is under greater pressure than physiologic conditions and mild ballooning of the calyces as well as occasional extravasation can occur normally.
Imaging of the bladder is performed with a cystogram, for which a catheter is placed into the bladder and contrast material is then injected. The contrast material is optimally injected under fluoroscopic observation but occasionally is performed with only static conventional radiographs, such as in the trauma setting. Anatomic considerations and evaluation are similar to the IVU with a few caveats. One advantage to cystography is that vesicoureteral reflux can be evaluated during the conventional cystogram unlike during IVU. Recently, CT cystography, in which after contrast instillation CT imaging is utilized instead of conventional films, has been used, especially in the setting of trauma to evaluate for bladder injury.
The urethra may be evaluated with contrast material via two methods. In one, the urethra is evaluated during voiding, often following a cystogram (voiding cystourethrogram or VCUG). Alternatively, a retrograde study may be performed (retrograde urethrogram). The urethra in the male consists of four portions, including the prostatic, membranous, bulbous, and penile portions. During voiding, the urethra is fairly uniformly distended and tubular in appearance. On a retrograde study, the more posterior urethra (prostatic and membranous) is often contracted and seen as a thin wisp of contrast. The female urethra appears as a short, slightly funnel-shaped tubular structure during voiding. The urethra in males is generally evaluated for injuries but may also be examined for filling defects, masses, strictures, and fistula. The female urethra is most commonly examined for diverticula.
Ultrasonography is a useful technique for evaluation of the urinary tract, made especially attractive by its ease of use and lack of complications (no contrast material or ionizing radiation). The kidneys are generally well seen in all but the largest of patients. The renal medulla is hypoechoic (darker) relative to renal cortex and can be identified in most normal adults as cone-shaped central structures. (Occasionally, this corticomedullary distinction is not visible.) The renal cortex is isoechoic or slightly hypoechoic compared with the echogenicity of the adjacent liver. In addition to echogenicity, the kidneys should be assessed for size, location, and symmetry. Scarring and masses can be evaluated. Unlike the IVU, where masses are often nonspecific, ultrasonography allows a more detailed evaluation including the ability to confidently diagnose the most common renal mass—the simple cyst. Solid masses, however, remain nonspecific and generally require further evaluation.
The renal sinus is the area engulfed by the kidney medially, harboring the renal pelvis, arteries, veins, nerves, and lymphatics that enter and exit the kidney, all contained within a variable amount of fat. Fat is typically brightly echogenic on ultrasound, and fat within the renal sinus dominates the ultrasonographic appearance, creating what is known as the central echo complex. The size of the central echo complex is variable, often more prominent in the elderly and minimal in the child. Absence of the central echo complex may suggest a mass such as a transitional cell carcinoma replacing the normal fat. Alternatively, the complex may be very prominent in the benign condition of renal sinus lipomatosis.
Calcifications are characteristic on ultrasound, being brightly echogenic and resulting in shadowing posteriorly as the sound waves are attenuated. Renal stones or calcifications may be detected within the renal parenchyma or in the intrarenal collecting system. The echogenicity of the normal renal sinus, however, creates difficulty because sometimes it obscures or mimicks small stones.
Ultrasonography is also excellent for detecting hydronephrosis with the distended collecting system being easily recognized within the central echo complex. The ureters are not normally seen on ultrasound due to obscuring overlying tissue and their small size. Evidence of their patency may be verified by Doppler detection of urine rapidly entering the bladder from the distal ureters, i.e., distal ureteral jets.
The bladder is seen as a rounded or oval anechoic (fluid) structure in the pelvis. The bladder may demonstrate mass lesions, such as transitional cell carcinoma, or stones. The urethra is not typically seen on an ultrasound image although urethral diverticula may occasionally be demonstrated.
CT is now the dominant radiologic imaging modality for evaluation of the urinary tract. The high contrast resolution and spatial resolution afforded by CT allow detection and evaluation of subtle differences in very small structures. Mathematical calculations of the attenuation of the CT x-ray beam allow quantitative evaluation of the relative density of structures (i.e., their Hounsfield units), and it is through these "CT numbers" that much unique diagnostic information of the urinary tract is gained. Examinations can be performed amazingly fast because thin-slice CT scans of the entire urinary tract are now obtainable in just a few seconds. Finally, the wide availability and relative safety of CT furthers its appeal. CT scans of the urinary tract may be performed with and/or without intravenous iodinated contrast material depending on the indications. Noncontrast studies may be performed to evaluate stone disease and other calcifications. Additionally, noncontrast views of the kidneys serve as a baseline to evaluate for lesion enhancement after contrast administration, a critical factor in mass evaluation. On noncontrast examinations the kidneys are homogeneous and have a density similar to most soft tissue.
Contrast-enhanced studies of the kidneys are best performed with a mechanical power injector. With rapid scanning and contrast bolus timing, several sequential phases of opacification within the kidney can be delineated by CT including corticomedullary, nephrographic, and excretory phases. The corticomedullary phase can be seen if scanning is performed during the first 20 to 90 seconds after contrast administration and represents the early preferential blood flow to the renal cortex; however, small masses could be missed during this phase, being obscured within the unenhanced renal medulla. Subsequently, contrast begins to pass into the distal collecting tubules within the renal medulla, resulting in a more homogeneous opacification of the renal parenchyma, termed the CT nephrographic phase. This generally occurs around 2 to 4 minutes after contrast medium injection. Finally, the excretory phase is seen when contrast opacifies the collecting system. Each different phase of opacification may better demonstrate different disease processes and thus various scanning protocols are used to evaluate the kidneys depending on the indication. One of the major recent advances in imaging has been the ability to noninvasively evaluate the vascular system, and thin-section early CT images accurately demonstrate the main arterial and venous structures of the kidney. Just as with IVU or any modality, the kidneys should be evaluated for position, orientation, size, and radiographic density. Unlike IVU, however, CT provides much greater specificity regarding renal
disease, including mass lesions.
The ubiquitous simple cyst is generally easily diagnosed and differentiated from the more concerning solid mass. Fat within a solid mass generally allows the diagnosis of the benign angiomyolipoma. The solid, non-fat-containing mass in the adult should be considered a renal cell carcinoma until proven otherwise. CT is sensitive in detecting renal masses and, although not always supplying a specific diagnosis, typically provides important information allowing for appropriate patient management. The remainder of the retroperitoneum, containing fat, the normal occupants of the retroperitoneum (kidneys, adrenals, pancreas, duodenum, and parts of the colon), and vascular structures, is well seen by CT, and diseases such as inflammation, infection, and tumor are easily demonstrated.
CT is also useful in staging renal neoplasms. Non-neoplastic renal disease, such as trauma and complicated infections, is accurately demonstrated on CT images, which provide specific information regarding the extent and severity of the process.
Until recently, the ureters and their disorders were the domain of the IVU or retrograde pyelogram. First, the invention of spiral CT technique allowed for continuous coverage of the entire ureter without skip areas. Second, virtually all stones are dense and conspicuous on CT. There are many other advantages to using CT to evaluate suspected ureteral stones including speed of the examination, identification of alternative explanations for the pain (appendicitis, diverticulitis, aneurysm, etc.), and elimination of intravenous contrast complications (because the study is performed without contrast). The ureter can be visualized and followed from the renal pelvis to the bladder in most cases and appears as a tubular 2- to 3-mm fluid structure surrounded by retroperitoneal fat. Stones can be diagnosed by their high density and location within the ureter.
On CT, the bladder appears as a rounded water or contrast density structure in the pelvis. One pitfall is that the first few images of contrast beginning to enter the bladder may mimic a bladder mass. The bladder wall should be evaluated for thickening and irregularity, which may suggest hypertrophy, inflammation, or carcinoma. Stones may be detected within the bladder. The urethra is not normally seen on CT.
Just like CT, technical advances in magnetic resonance (MR) imaging have led to increasing use in urinary imaging. Fast-scanning techniques that allow breath-hold imaging, combined with the spectacular tissue contrast of MR imaging and the ability to directly image in any plane, make this an attractive modality for evaluating the urinary tract. Lack of ionizing radiation adds to its appeal, but cost, availability, claustrophobia, and the contraindication of certain materials including pacemakers remain major drawbacks. Finally, MR imaging of the kidney is performed with gadolinium as the contrast agent, not iodinated contrast material. In renal imaging one of the main advantages of gadolinium versus iodine is the virtual lack of nephrotoxicity at clinical doses. On MR imaging, the kidneys appear to be of variable signal intensity, depending on the imaging factors and, like CT, contrast-enhanced phases of imaging (arterial, corticomedullary, nephrographic, and excretory) are all visible. The ability to image in any plane creates a unique advantage for MR imaging.
The kidneys should be evaluated in a fashion similar to that of other modalities. Recently, two techniques have been developed to allow the ureters to be evaluated. In one method, the high signal intensity of water (urine) is utilized to make the ureters conspicuous compared to other tissues. In the other technique, the MR imaging contrast agent gadolinium is given and the ureters opacify similar to IVU or contrast-enhanced CT. The bladder is well visualized, similar to CT. Finally, the adrenal glands are well seen, as in CT, and the normal shape is the same as that described for CT and the signal intensity depending on particular imaging parameters. The ureters, bladder, and adrenals are evaluated in a fashion similar to that used for CT.
The value of nuclear imaging in the urinary tract is several-fold: Functional information related to quantifiable collected data is obtained, the radiation dose is lower than that for traditional radiographic techniques, and the incidence of complications is very low. Renal evaluation is typically performed by intravenous bolus injection of renal-specific agents. Images are acquired every few seconds that demonstrate renal blood flow, with additional images obtained over several minutes that show renal uptake and excretion. The recorded data can be used to produce images, but are also quantifiable and employed to generate time–activity curves. Information about renal perfusion, morphology, relative function of each kidney, and excretion can be extremely useful in evaluation of conditions such as renovascular hypertension, obstruction, and renal transplant examination. Although anatomically oriented data can be obtained with other radioisotopes that aggregate more in the renal parenchyma, in general, nuclear medicine renal studies suffer from fairly low spatial resolution and, therefore, are often used in conjunction with other imaging studies.
Radionuclide cystography is another useful test used to diagnose and monitor vesicoureteral reflux. Here, technetium pertechnetate is mixed with saline and infused into the bladder with subsequent images obtained over the urinary tract. This study is quite sensitive for the detection of significant reflux but at a considerably lower radiation dose than conventional cystography.
The role of angiography as a diagnostic tool continues to diminish with the increasing accuracy of noninvasive techniques to evaluate the vascular system. The renal arteriogram is performed after puncture of a more peripheral vessel such as the common femoral artery, with advancement of a catheter into the renal artery origin. Contrast material is injected via the catheter and rapid, typically digital, conventional radiographic images are obtained. The renal arterial vessels are well demonstrated, along with nephrographic images of the kidney and views of the venous drainage. Delayed images may be obtained to demonstrate the renal collecting system. The still superior spatial resolution of angiography permits detailed evaluation of the renal arterial supply and has a small but important diagnostic role in evaluating the small vessels of the kidney for such diseases as vasculitis and fibromuscular dysplasia.
The angiogram plays little role in diagnostic evaluation of the renal parenchyma, having been supplanted by cross-sectional imaging techniques. Compared to CT and MR, conventional angiography still has superior resolution for small-vessel evaluation. Thus, diagnostic angiography may play a role in diagnosis of small-vessel renal disease such as polyarteritis nodosa. More importantly, unlike CT and MR, catheter angiography allows for the ability to simultaneously treat abnormalities diagnosed at the time of angiography.
No one ideal technique is yet available for the comprehensive evaluation of the urinary tract. Each technique has strengths and weaknesses that affect their thoroughness and accuracy in evaluating urinary tract diseases and also patient complaints. Importantly, imaging techniques are not necessarily exclusive and in some circumstances are complementary — taken alone they may not provide enough information but together allow a correct clinical diagnosis. A knowledge of which tests are most appropriate for a given clinical question is paramount for physicians involved with the treatment of urinary tract disease. Issues of cost, complications, and time are consequences of an injudicious study choice. However, most importantly, the diagnosis of a patient's condition may not be made unless the appropriate test has been used to evaluate the condition.