Diagnostic Studies and Techniques in the Urinary Tract

Sergio G. Moreira, Jr., M.D.
Clinical Assistant Professor, University of South Florida, Tampa, FL
19111 Centre Rose Blvd, Lutz, FL 33558
moreiraurology@hotmail.com

Michael Keating, MD –
Clinical Professor of Urology, University of South Florida, Tampa, FL
Nemours Clinic, Orlando, FL
mkeating@nemours.org

Urinary Tract Imaging

Imaging plays an integral role in urologic diagnosis. Radiographic evaluation can be as simple as an abdominal plain film or as complex as a triphasic CT study. Imaging data can provide static anatomic information or functional data such as that obtained by excretory urography showing delayed contrast material excretion because of ureteral obstruction.

Abdominal Plain Radiography

An abdominal plain radiograph is most often referred to as a *KUB* (kidneys, ureters, and bladder). An anteroposterior radiograph of the abdomen may also be referred to as a *scout film* before the administration of IV contrast material for an IV urogram.

Field Imaged

A plain radiograph of the abdomen and pelvis includes the area above both adrenal glands and extends to 2 cm below the symphysis pubis. Sometimes two films are required to cover the entire area.

Indications

There are two reasons to obtain a plain abdominal radiograph: (1) as a primary study and (2) as a scout film before contrast material injection. Its most important function is for the demonstration of urinary tract calcifications, because excreted contrast material in the urinary tract often obscures calcifications within the collecting system. Also, abnormalities of the skeleton, abnormalities of the intestinal gas pattern, and some soft tissue abnormalities may be detected.

Excretory Urography

Indications

Excretory urography (EXU) allows visualization of the entire urinary tract. The study provides demarcation of the renal parenchyma, the pyelocalyceal system, ureters, and bladder, providing both anatomic and functional information. EXU is indicated in patients being evaluated for hematuria and/or urolithiasis. CT scan is, however, replacing EXU for the diagnosis of acute stone disease. In trauma, when the patient is already in the operating room, **a one-shot EXU (1 ml/pound of body weight of contrast material and obtaining either a series of films at 1, 5, 15, and 30 minutes or a single film at 10 minutes),** can provide information on the continuity of the urinary tract and the function and number of renal units.

Contrast Media

Since their development in the 1950s, triiodinated benzoic acid derivatives have been used for opacification of the urinary tract. Most ionic contrast agents are hypertonic, with dissociating cations of either sodium or methylglucamine. Monomeric ionic agents are often referred to as *high osmolar contrast media* (HOCMs). Renografin, Hypaque, and Conray are members of this class of agents. These substances are excreted by glomerular filtration, and thus the degree of opacification is determined by the dose of contrast medium administered and the patient's glomerular filtration rate (GFR). As the urine is concentrated, the relative concentration of the contrast agent is increased 50- to 100-fold compared with plasma. **A major disadvantage of these agents is their hypertonicity, with a mean osmotic load of 1400 to 2400 mOs/kg H_2O, exceeding that of serum by a factor of 5 to 7**. **The hypertonicity of the contrast media may have ill effects on the cardiovascular system, the coagulation cascade, the blood-brain barrier, and the kidneys.**

In order to reduce the osmolality and therefore the toxicity of contrast media, low osmolar contrast media (LOCMs) were developed. **This class of compounds provides an approximately 50% reduction in osmolality with an equivalent iodine load but until recently had been 5 to 10 times more expensive than the older HOCMs**

Iodinated contrast agents have several physiologic effects owing to either their hypertonicity or their chemotoxicity. Many of the effects caused by hypertonicity are lessened with LOCMs. HOCMs can cause increased cardiac output and decreased peripheral vascular resistance by expanding the intravascular space. Peripheral vasodilatation can result in reflex tachycardia. **Bradycardia** has also been reported and thought to be due to direct vagal or sinoatrial node activation.

Adverse Effects of Contrast Media

Adverse effects of contrast media are generally classified into two large groups—chemotoxic effects and idiopathic or anaphylactoid reactions. Chemotoxic effects are thought to be dose related and the result of a direct toxic effect of the contrast media on the target organ. The most important chemotoxic effect is **nephrotoxicity**. Anaphylactoid or idiosyncratic reactions are so named because they simulate a true anaphylactic reaction but are not mediated by immunoglobulins.

Contrast-Associated Renal Dysfunction

Contrast media may induce an acute impairment of renal function, defined as an increase in the serum creatinine level of 0.5 to 1 mg/dl or a 25% to 50% decrease in the GFR or both. The most consistent predictor of CARD is preexisting underlying renal insufficiency. Those patients at high-risk for contrast-induced nephropathy may be more susceptible when dehydrated and when exposed to high doses of contrast agents. Therefore, in high-risk patients, adequate hydration, **avoidance of dehydrating preparations**, and a **reduction in the dose** of the contrast agent may be beneficial. Multiple myeloma has also been reported to be a risk factor for the development of renal failure. The mechanism in such cases is thought to be the precipitation of myeloma proteins within the tubules, but this may be prevented with adequate hydration.[21]

A new risk of contrast media has been identified for patients whose diabetes is managed with **metformin (Glucophage),** an oral antihyperglycemic agent whose mechanism of action is to decrease hepatic glucose production and to increase its peripheral utilization. Because of this mechanism of action, there is no risk of **hypoglycemia.**[35] Metformin is excreted unchanged by the kidneys. The major manifestation of metformin overdosage is the development of lactic acidosis. Thus, patients taking metformin who receive contrast material are at risk for **lactic acidosis** only if renal failure occurs as a result of contrast-induced nephrotoxicity. **In order to minimize this risk, the U.S. Food and Drug Administration has recommended that patients taking metformin who receive contrast material have the drug withheld for 48 hours after receiving contrast material.**

Retrograde Pyelography

Technique

Retrograde pyelography (RP) is the opacification of the ureter and pelvicalyceal system by the retrograde injection of contrast media through a ureteral catheter under cystoscopic guidance, since the procedure requires visualization of the ureteral orifice. **The procedure must be performed under sterile conditions and is contraindicated in a patient with infected urine because of the risk of introducing bacteria into the upper collecting system or blood stream.**

Indications

RP is most often employed after an excretory urogram that inadequately visualized the anatomy of the upper tract. Additionally, RP is used to better demarcate a filling defect found during an EXU and to delineate suspected renal pelvic and ureteric abnormality. RP is also routinely performed during various ureteral manipulations including stent placement, laser lithotripsy, and biopsy. Occasionally, RP is performed in patients in whom IV contrast material is contraindicated.

Cystourethrography

Technique

Contrast-enhanced imaging of the lower urinary tract provides valuable information on the function and anatomy of the bladder and urethra. Contrast agents can be injected either in a retrograde fashion through a Foley catheter or in an antegrade manner through a suprapubic tube. Imaging can be performed with either plain film radiography, fluoroscopy, or videofluoroscopy.

Static Cystogram

A static cystogram of the bladder is obtained by retrograde filling of the bladder through a Foley catheter. An initial scout film is obtained before the injection of contrast material. The scout film provides information on abnormal calcifications of the pelvis that may interfere with interpretation of the postdrainage film. The bladder is filled under gravity with a 30% to 60% solution of water-soluble contrast agent. In the adult with a normal bladder capacity, a minimum of 350 ml of contrast material is required for an adequate evaluation of bladder continuity. After a radiograph of the filled bladder, the bladder is drained through the Foley catheter and a postdrainage film is obtained. A static cystogram provides information on bladder volume, contour, and continuity.

Voiding Cystourethrography

Voiding cystourethrography (VCG) is a widely applied radiographic technique for the evaluation of the bladder and urethra in children and adults. **VCG allows evaluation of the bladder and urethra during the physiologic act of micturition, providing visualization of the posterior urethra.** The bladder is filled in a retrograde manner with water-soluble contrast material. The catheter is withdrawn, and the patient voids while radiographic visualization is performed and select spot films or video-recording of the procedure or both are obtained

Retrograde Urethrography

Retrograde urethrography (RUG) provides excellent visualization of the anterior urethra in the male.The study involves retrograde filling of the anterior urethra with a 30% to 60% solution of water-soluble contrast material. A No. 14- to No. 16-Fr Foley catheter is placed 1 to 2 cm into the urethra. Little to no lubricant is used so that the catheter is not easily expelled during injection.

Indications

Static cystography is commonly used to evaluate the continuity of the bladder. It is useful in the postoperative patient to exclude extravasation. In trauma, cystography is useful to define the presence and the degree of bladder injury. It is prudent, however,

to perform RUG before inserting the Foley catheter in patients with significant pelvic trauma. This maneuver excludes concomitant urethral injury and prevents further urethral injury during catheter placement. Static cystography is also employed in evaluating bladder diverticula and fistulas.

The retrograde urethrogram is an excellent study to evaluate the male anterior urethra. The primary indications for RUG are urethral or pelvic trauma, urethral strictures, diverticula, and fistulas. **The posterior urethra is not well visualized during RUG.**

The posterior urethra is best evaluated by VCG. For example, VCG is the study of choice in evaluating male infants with presumed posterior urethral valves. VCG is the primary means of evaluating the female urethra. VCG is routinely used to evaluate vesicoureteral reflux in both children and adults. VCG is also employed during evaluation of the patient with voiding dysfunction.

Ultrasonography

Principles

Ultrasonography is a painless and noninvasive method of using high-frequency sound waves to image anatomic structures and provides valuable information regarding renal morphology and perfusion. Ultrasonography has many advantages including availability, flexibility, lack of ionizing radiation, and accurate anatomic and, sometimes, physiologic information obtained without the need for intravascular contrast agents. Ultrasonography is not function dependent. Characteristics of blood flow can be determined. Ultrasonography also has limitations; with respect to the kidney, it has inferior resolution compared with EXU. It also provides no functional information. Ultrasonography depends on both the operator's experience and the quality of the ultrasonographic equipment to produce consistently high-quality studies.

Computed Tomography

Principles

General

CT images are produced because of attenuation of x-ray photons by the patient. CT uses a computer to mathematically reconstruct a cross-sectional image of the body from measurements of x-ray transmission through thin slices of the patient's tissue. The data obtained is systematically repeated many times while a series of exposures from different projections is made as the beam rotates about the patient.

Spiral (Helical) CT

Spiral CT, also called *helical* or *volume-acquisition CT*, is performed by advancing the patient on the gantry during simultaneous tube rotation with continuous x-ray exposure (slip-ring technology). The 1-second or less tube rotation coupled with continuous forward movement of the table permits the volumetric acquisition of patient data during the suspension of breathing. The faster examination is of particular value in assessing patients after acute trauma. Spiral CT has the ability to reconstruct overlapping images at arbitrary intervals, improves the visualization of small lesions and vasculature, and allows high-quality CT angiography with 3D reconstruction and multiplanar two-dimensional reformation displays. Helical CT continues to evolve with the introduction of new-generation CT scanners.

Contrast Media

Oral Contrast Agents

Oral contrast agents are routinely administered before scanning to opacify the bowel to help differentiate bowel from tumors, lymph nodes, and hematomas.

Intravenous Contrast Agents

General

A contrast agent–enhanced study is essential for complete evaluation of the urinary system in order to demonstrate alterations in renal excretion of contrast agents that may occur as the result of a pathologic process.

Triphasic Imaging

Renal enhancement on CT after IV contrast material administration can be categorized in four phases: vascular, cortical nephrographic, diffuse nephrographic, and excretory. Spiral CT can image particular phases of the nephrographic progression. The identification of global or regional nephrographic abnormalities during a particular phase of contrast agent enhancement is of value in assessing renal perfusion and function. Renal arteries are evaluated during the vascular phase, approximately 15 to 25 seconds after IV contrast material administration. In the excretory phase, contrast material in the collecting system starts to appear approximately 3 to 5 minutes after contrast material administration.

Indications

Kidney

CT is an excellent modality for evaluating renal masses and is almost as accurate as ultrasonography for differentiating cysts from solid lesions. **CT can accurately characterize the nature of tissue in the lesion.** Also, lesions can be evaluated for enhancement during IV contrast agent administration in order to determine increased or decreased blood flow. **CT is useful in the preoperative evaluation and staging of tumors.** Thrombus of the renal vein or inferior vena cava can be adequately assessed using spiral CT. CT can readily recognize perinephric abscess, urinoma, and hematoma. **CT has replaced IV urography as the primary modality for the assessment of suspected renal injuries and their complications.**

Stone Disease

For the evaluation of patients with acute flank pain, unenhanced spiral CT is more sensitive in detecting calculi than EXU.

Bladder

CT has long been the primary imaging modality for staging carcinoma of the bladder. With CT, the presence or absence of perivesical spread can be gauged with an accuracy of 75% to 80% and obvious lymphadenopathy can be detected. However, MRI shows promise of possibly surpassing CT as the dominant imaging study in bladder cancer.

Prostate and Seminal Vesicles

With CT, congenital anomalies, cysts, and abscesses of the seminal vesicles can be well visualized and prostate abscesses can be detected. CT, however, has been replaced by MRI in assessing the extent of carcinoma of the prostate.

Adrenal

CT has become the study of choice for the initial evaluation of any patient with suspected adrenal masses. Most adrenal masses are incidentally detected by CT. Benign cortical adrenal adenomas are often discovered as an incidental finding and have been reported in 2% of patients undergoing abdominal CT. **An adrenal adenoma can be differentiated from metastases when the lesion measures equal to or less than 10 Hounsfield units (HU) on unenhanced CT, and no further work-up is necessary.**

Renovascular

Spiral CT angiography has become an effective noninvasive imaging modality for evaluating the renal vasculature. The current clinical applications for CT angiography and 3D imaging related to the kidneys and renal vasculature include the noninvasive assessment of renal arterial stenosis.

Magnetic Resonance Imaging

Principles

When a patient is placed in a large magnetic field, the hydrogen protons within the body align, and this alignment leads to the formation of a net magnetic vector within the patient. By applying radiofrequency pulses to the patient, this vector can be made to spin. An antenna (coils) lying outside the patient in the magnet has a current induced within it by the spinning bar magnet. This current originates from the tissues, and its magnitude is related to the intensity of the pixel in the MRI image. When this information is digitized and processed, cross-sectional anatomic images of slices of the body are provided.

MRI can generate direct multiplanar images and provide specific information. Blood vessel MRI is known as *magnetic resonance angiography* (MRA). Frequency-selective fat saturation techniques to suppress fat signals may be useful when the kidneys are bright (e.g., using T_2-weighted or gadolinium-enhanced T_1-weighted images). Magnetic resonance (MR) urography is another potential application of MRI.

Contraindications to an MRI, include: Patients with pacemakers, claustrophobia, ferromagnetic intracranial aneurysm clips, cochlear implants, metallic ocular foreign bodies, and certain older heart valve prostheses cannot be safely imaged.

MRI Contrast

Gadolinium is a paramagnetic lanthanide metal with unpaired electrons. Gadolinium chelates are freely filtered by renal glomeruli and undergo excretion by renal tubules with no tubular reabsorption or excretion.

Side effects of gadolinium chelate contrast agents used for the examination are rare. **MRI contrast agents are not usually nephrotoxic and have a low frequency of allergic reactions in contrast to iodinated radiographic contrast agents**.

MRI with contrast is safe for use in patients with impaired renal function as well as in patients with a history of allergic reaction to iodinated contrast material.

Pulse Sequences

Superior soft tissue contrast resolution is one of the greater advantages of MRI over CT. MRI contrast arises from a complex relationship between many different factors including proton density, T_1, T_2, magnetic susceptibility, and flow. Most tissues can be differentiated by significant differences in their characteristic T_1 and T_2 relaxation. **T_1 is a measure of a proton's ability to exchange energy with its surrounding chemical matrix and is a measure of how quickly a tissue can become magnetized. T_2 conveys how quickly a given tissue loses its magnetization.**

Nuclear Imaging

The unique functional information obtained by radiopharmaceuticals can be very useful in the management of patients with various renal diseases. Early physiologic changes can be detected, often before the clinical manifestation of disease. A majority of the radiopharmaceuticals used in the past were radioiodine-labeled agents, but currently, numerous technetium Tc 99m (^{99m}Tc)–labeled agents are used in genitourinary scintigraphy. **The radionuclides currently available can measure perfusion, functional morphology (glomerular filtration and tubular secretion)**, **excretion, and cortical morphology.**

Table 1 -- Common Radiopharmaceuticals

[*] DMSA, technetium Tc 99m dimercaptosuccinic acid;

[†] DTPA, technetium Tc 99m diethylenetriaminepenta-acetic acid;

[‡] GHA, technetium Tc 99m glucoheptonate;

[§] MAG3, technetium Tc 99m mercaptoacetyltriglycine;

[£] ^{123}I-OIH, orthoiodohippurate I 123;

[¶] ^{131}I-OIH, orthoiodohippurate I 131.

I. Glomerular filtration agents

- **A.** ^{99m}Tc diethylenetriaminepenta-acetic acid (^{99m}Tc-DTPA) (glomerular filtration solely)
- **B.** ^{99m}Tc glucoheptonate (^{99m}Tc-GHA) (glomerular filtration and cortical binding)

II. Renal tubular agents

- **A.** ^{99m}Tc mercaptoacetyltriglycine (^{99m}Tc-MAG3) (some glomerular filtration, more tubular secretion)
- **B.** Iodohippurate (OIH) I 131 or I 123 (maximal tubular secretion and glomerular filtration)

III. Renal cortical morphology

- **A.** ^{99m}Tc-GHA
- **B.** ^{99m}Tc dimercaptosuccinic acid (^{99m}Tc-DMSA)

IV. Miscellaneous agents

- **A.** Gallium citrate Ga 67
- **B.** ^{99m}Tc pertechnetate (^{99m}Tc-TcO$_4$)

V. Renal transplant evaluation agents

- **A.** ^{99m}Tc-MAG3
- **B.** ^{99m}Tc-DTPA
- **C.** ^{131}I-OIH
- **D.** ^{123}I-OIH

Choice of Renal Radiopharmaceutical

In clinical practice it is important to differentiate between a renal **hemodynamic problem** and one involving the renal parenchyma. Several renal agents are useful for the determination of blood flow. However, the agent of choice depends on what physiologic function one would like to evaluate**.** In patients with severe renal dysfunction, tubular agents such as ^{99m}Tc-MAG3 and ^{131}I-OIH, usually allow better visualization of the kidney.

Renal scintigraphy is generally indicated in the evaluation of renal perfusion, function, or drainage, or to rule out obstruction, or all of these.

Ideal characteristics of a renal function agent would include the following:

1. The ability for rapid distribution of tracer throughout the kidney
2. High target-to-background activity
3. Relatively rapid excretion
4. No other route of excretion

Glomerular Filtration Agents

These radiopharmaceuticals are cleared primarily by glomerular filtration and are neither reabsorbed nor secreted by the renal tubules. A pure glomerular agent would resemble inulin and would have no protein binding. ^{99m}Tc-DTPA is the most commonly used isotope for determining GFRs, and the normal range is between 100 and 120 ml/min.

Renal Tubular Agents

The clearance of agents that are nearly completely extracted from the renal blood can be used to determine renal plasma flow. The difficulty of finding an agent that is completely cleared in a single pass has led nephrologists to adopt an effective renal plasma flow. No agent completely satisfies the requirement of complete extraction.

In 1986, a ^{99m}Tc-labeled tubular agent named **^{99m}Tc-MAG3**, was introduced to the medical community. . As this agent is labeled with ^{99m}Tc, it is suitable for flow imaging. As it is cleared by tubular secretion predominantly, it may be used to measure renal plasma flow. MAG3 can also be used to evaluate **renal excretory function**. In healthy individuals with normal renal function, ^{99m}Tc-MAG3 is rapidly cleared from the blood. The $T_{1/2}$ for clearance is approximately 17 minutes. Split renal function can also be obtained. In individuals that have a history of neurogenic bladder, urinary diversion and children, a Foley catheter should be used to decompress the lower urinary tract in order to avoid false-negative readings.

ENDOUROLOGY

Endourology has evolved in the past decade as a technology for diagnosing and treating urological diseases in a manner that obviates the need for open surgery. It can be performed from the urethra to the kidney. Direct visualization of the anterior and posterior urethra, bladder neck, and bladder is accomplished by cystourethroscopy, which has been in use for over 100 years. Since then, many improvements in endoscopes were made and today, with digital technology and advances in fiber optics, the quality of instruments is second to none. Still, there is a need for a irrigant (water, sorbitol or saline), a light source and most urologists in this era are trained with video cameras. Cystourethroscopy is used to directly visualize the lower urinary tract anatomy and macroscopic pathology, which may be responsible for the clinical picture under evaluation. In addition, material for both cytologic and histologic examination can be obtained using cystourethroscopic techniques. One of the most common indications for cystourethroscopy is in the evaluation of microscopic and **gross hematuria**. Diagnostic contrast examination of the entire upper urinary tract is accomplished by retrograde injection of contrast agents through small catheters passed cystoscopically**. Fluoroscopy** is used in conjunction with these diagnostic and therapeutic procedures of the upper urinary tract. It is important to ensure that the patient does not have an active urinary tract infection before cystourethroscopy, because of the possibility of exacerbating the infection by instrumentation of the urinary tract.

If electrocoagulation is planned, it is necessary to avoid solutions containing electrolytes.

Technique

Systematic inspection of the entire urethra and bladder should be performed during cystourethroscopy. Prior to insertion of the instrument, the urethral meatus should be inspected if this has not already been accomplished. If the meatal size appears inadequate to accept the endoscope, it can be dilated with metal sounds.After the sheath of the cystourethroscope is generously lubricated with a water-soluble anesthetic-lubricant, the endoscope can be passed under direct vision with a 0- to 30-degree lens, remembering the urethral anatomy.

In the male, the penis should be grasped and straightened so that it forms almost a right angle to the abdominal wall. The external sphincter is easily identifiable at the level of the membranous urethra by the mucosal folds radiating from a narrow lumen ahead of the endoscope. Gentle pressure facilitates passage of the endoscope through this area. When the instrument passes into the prostatic urethra, the verumontanum is noted. At the level of the bladder neck, it may be necessary to depress the endoscope gently in order to pass the instrument into the bladder over the bladder neck. An alternative technique is to pass the rigid endoscope “blindly” into the bladder as one would pass a metal dilator, with inspection of the urethra on withdrawal of the endoscope.

Once the endoscope is inside the bladder, a systematic evaluation of the **entire bladder** surface is performed. Using the 30-degree lens with the bladder only slightly filled, one can identify the interureteric ridge just inside the bladder neck along the trigone. Next, the ureteral orifices are visually located several centimeters lateral from the the endoscope from anterior to posterior and back as the bladder fills slowly.

The urologist should have a systematic method of performing cystourethroscopy

Endoscopy of the upper urinary tract should always be performed with a guide wire that goes from the bladder to the kidney. This is important, because if a perforation occurs and if anything that prompts the procedure to be terminated, a stent can be left in place assuring drainage of that unit. Also, if multiple entries in the ureter are needed the wire serves as a guide. It is also important to always visualize the wire on the center of the picture to avoid false-passages. When one uses a flexible ureteroscope for renal procedures (stones, tumors), an access sheath is a very valuable tool. Balloon diation of the ureteral orifice is optional and a stent must be placed at the end of the procedure if dilation takes place.

The most important rule in endourology: "never force your way through". Endoscopic procedures must be smooth and atraumatic.

Endourology aldo includes percutaneous techniques that provide access to the urinary tract from an antegrade approach. Many open procedures for stone disease or drainage of infected kidneys have been replaced by this technique. Treatment of large stones, ureteral stricures and even urothelial tumors is now possible in a minimally invasive fashion.

References:

1. Moreira SG, Pow-Sang J. Evaluation and management of adrenal masses.
Cancer Control. 2002 Jul-Aug;9(4):326-34. Review.

2. Walsh**:** Campbell's Urology, 8th ed. 2002 Elsevier

3. Morris PJ, Malt RA, Oxford Textbook of Surgery