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E. G. Nordio, N. V. Tumanskaya, T. M. Kichangina, Myagkov S.A.

RADIOLOGICAL INVESTIGATIONS OF THE UROGENITAL SYSTEM

MANUAL

for the students of the 3rd course of international faculty speciality "General medicine" English medium of instruction

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Authors:

E.G. Nordio – assistant of department multimodal diagnostic and propedeutic ZSMU;

N.V. Tumanskaya – Candidate of Medical Sciences, assistant professor of department multimodal diagnostic and propedeutic ZSMU;

S.A.Myagkov – Candidate of Medical Sciences, assistant professor of department multimodal diagnostic and propedeutic ZSMU;

T.M.Kichangina – assistant of department multimodal diagnostic and propedeutic ZSMU;

Reviewers:

V. A.Vizir - doctor of medical sciences, professor of department of internal medicine №2 of the ZSMU;

V. M. Klimenko - doctor of medical sciences, professor of department of Faculty Surgery of ZSMU;

N78 **Nordio E. G., Tumanskaya N. V., Kichangina T. M., Myagkov S.A.**

Radiological imaging of the urogenital system : manual for the students of the 3rd course of international faculty speciality “General medicine” English medium of instruction / O.G. Nordio, N. V. Tumanskaya, T. M. Kichangina, S.A. Myagkov,. - Zaporozhye : ZSMU, 2019. – 109 p.

The manual provides the basics of radiological diagnostics (investigationss, principles for obtaining images, indications for the application of these methods, and radiation signs of the urogenital system pathology) for the independent preparation of students of the third year of the International Medical Faculty.

В посібнику представлені основи променевої діагностики (методи, принципи отримання зображення, показання до застосування цих методів, та променеві ознаки захворювань сечостатевої системи) для самостійної підготовки студентів III курсу міжнародного факультету з радіології.

CONTENTS

Introduction

The pace of innovation in diagnostic radiology has increased exponentially, in tandem with computer advances and the rapid evolution of microprocessing power. Imaging of the urinary tract, as a result, has become more flexible and precise, with new procedures offering a great selection of options, and new imaging algorithms being implemented. Ultrasonography, computed tomography (CT), and magnetic resonance imaging (MRI) provide higher soft-tissue contrast resolution than conventional radiography, as well as multiplanar imaging capability, resulting in significant advances in almost all areas of uroradiology. In academic centers, metabolic and molecular imaging techniques have become the focus of new research, and have begun to enter the realm of daily clinical practice. While imaging advances have produced new algorithms for approaching diagnostic evaluation, appropriate use of imaging in each particular case also depends greatly on the equipment and professional talent available. One imaging modality or protocol may offer specific advantages over another depending on the clinical question, and the importance of a collaborative approach from the medical team cannot be overemphasized.

In summary, ever changing uroradiology remains indispensable in the diagnosis and treatment of patients with urologic disorders.

Methods of investigations

Initial methods

Ultrasound

Plain radiograph

Intravenous urography

Additional methods

1. Non invasive

Doppler ultrasound

CT – scan

MRI

2. Invasive

Retrograde pyelography

Antegrade pyelography

Cystography

Cystourethrography

Nuclear medicine

PET scan

Renal angiography

CT angiography

MRI angiography

Urological interventions

1. *Ultrasound (US)*

Ultrasound is a useful technique for evaluation of the urinary tract, with its principal advantages including wide availability, no need for intravenous contrast material, and lack of ionizing radiation.

Indications

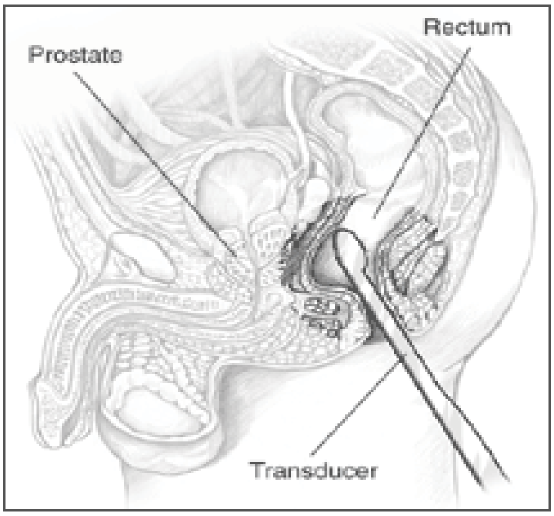
- renal size
- growth
- flank and/or back pain
- masses
- renal obstruction
- urinary tract infection
- hematuria
- congenital abnormalities
- renal failure
- abdominal trauma
- pretransplantation and posttransplantation evaluation
- transplants
- bladder residual volumes
- prostatic size
- planning and guidance for an invasive procedure

Abdominal ultrasound

In abdominal ultrasound, the technician applies a gel to the patient’s abdomen and holds the transducer against the skin. The gel allows the transducer to glide easily, and it improves the transmission of the signals. Abdominal ultrasounds are well known for taking pictures of fetuses in the womb and of a woman’s ovaries and uterus, but this approach can also be used to evaluate the size and shape of the kidneys.

Transrectal ultrasound

Transrectal ultrasound is most often used to examine the prostate. The transducer is inserted into the patient's rectum so that it is right next to the prostate. The ultrasound image shows the size and shape of the prostate and any irregularity that might be a tumor. To determine whether an abnormal-looking area is in fact a tumor, the doctor can use the transducer and the ultrasound images to guide a biopsy needle to the suspected tumor. The needle collects a few pieces of prostate tissue for examination with a microscope.



transrectal ultrasound.

Several common indications include evaluation of the patient with acute renal failure to exclude postobstructive (hydronephrosis) etiologies, to evaluate for sequelae (scarring) of vesicoureteral reflux in children, and to diagnose simple renal cysts. Ultrasound is generally the study of choice in evaluating the renal transplant as well.

However, the relatively small and sometimes technically limited (in large patients) field of view, lack of visualization of the ureters, and lack of functional assessment limit the use of ultrasound in some circumstances.

Additionally, solid renal masses are nonspecific on ultrasound and require further imaging, usually with CT. Ultrasound has only moderate sensitivity for detecting renal stone disease. Although the retroperitoneal position of the kidneys usually provides an excellent window for ultrasound, patients with a large habitus continue to become more common, and in these patients sensitivity for small masses or calculi may be markedly diminished.

The renal US should always be performed in combination with a complete upper abdominal ultrasound.

Preparation

Usually, patient does not have to do anything special to prepare for a renal ultrasound.

It is important that patient have a full bladder for this test.

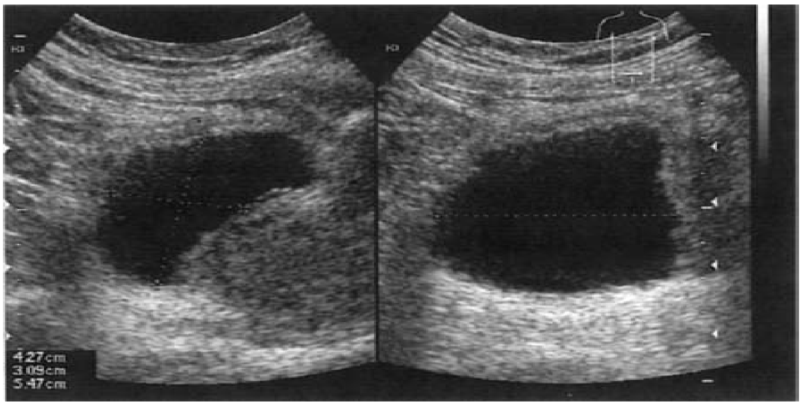
Procedure

Renal US is usually performed in supine position. The side to be examined can be slightly elevated. After visualizing the kidney from a posterior and lateral angle, the long axis of the transducer is aligned with the long axis of the kidney.

The resulting longitudinal cross sections are best suited to determining renal size and assessing cortical thickness as well as the configuration and size of the renal pelvis. The transducer is then rotated by 90 to scan up and down the kidney perpendicular to its long axis. As with all paired organs, comparison with the opposite side is essential for the evaluation of the images. Finally, cast an eye on the (hopefully) fluid-filled bladder.

The bladder volume can be estimated for most purposes by taking the product of three perpendicular measurements and multiplying by 0.56:

Bladder volume (ml) = length x *width* x *anteroposterior diameter (cm)* .x *0.56*



longitudinal section (LS) and TS scans through the bladder after micturition demonstrating an enlarged prostate (P) and a small residual urine volume of 40 ml

Anatomy

The kidneys lie parallel to the ribs lateral to the psoas muscles between the midscapular line and the posterior axillary line and between the eighth and eleventh ribs, although the location is subject to respiratory and individual variation. They can be imaged directly or, on the right, more laterally, using the liver as a window.

The normal kidney is less than 10 to 12 cm in length. Large or small size, as well as irregular contour, can be pathological. The renal capsule is highly reflective and thus is echogenic on ultrasound. Some patients have a surrounding rim of perinephric fat with a stippled heterogeneous appearance of intermediate echogenicity. The renal “cortex” is less echoic than the adjacent liver or spleen. The renal “medulla” is composed of renal pyramids (more hypoechoic than the cortex) and the columns of Bertini (extensions of the cortex between the pyramids), which comprise a layer surrounding the renal sinus. The latter is comprised of the collecting system, renal vasculature, and fatty tissue. In normal conditions, the collecting system contains no urine because ureteral peristalsis occurs every 10 s and is not seen on ultrasound. Renal sinus fat is highly echogenic; therefore, hypoechoic structures in the renal sinus seen on normal exam are vascular. Normal ureters are not visualized. The filled urinary bladder is echogenic with distinct even contours.

Routine examination of the bladder requires it to be moderately full. The normal bladder has a triangular shape in the sagittal plane, and that of a square with the corners rounded off in the transverse plane. The normal wall thickness is 2-3 mm when the bladder is moderately full.

Ultrasound can identify or confirm a distended bladder in suspected urinary retention and can also be used to estimate postvoid residual. In both settings, ultrasound obviates the more time-consuming and invasive test of catheterization. Many techniques have been assessed for estimating bladder volume, but the simplest, which has been shown to be no less accurate than any of the others, is to measure it in three orthogonal planes (length × width × height) to obtain a rough estimate. Some advocate multiplying this product by 0.75.

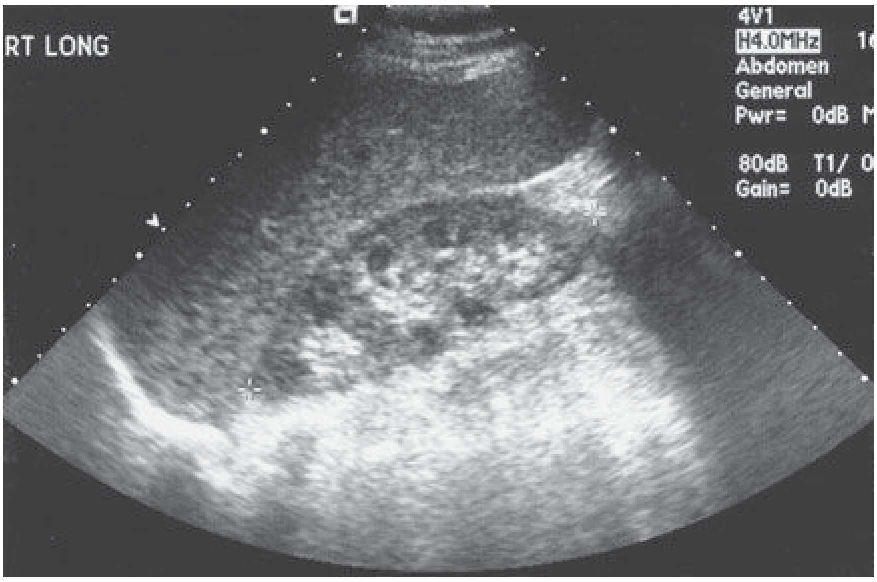
The bladder walls should be scanned for irregularities.

The prostate can be seen at the bladder base on routine transabdominal scanning of the bladder. The normal prostate is roughly bean shaped, the concavity of the bean facing posteriorly. The transitional and central zones have the same intermediate echogenicity and are inseparable on ultrasound. They can be referred to as the central gland, and increase in volume and heterogeneity with age as benign prostatic hyperplasia develops in the transitional zone. The peripheral zone is seen as an echogenic layer lying posteriorly. It is the site of most prostatic tumours, which usually appear as relatively echo-poor areas. Normal prostatic dimensions in the adult male are approximately 4 cm in the craniocaudal and transverse planes and 3 cm in the anteroposterior plane, with a maximum volume of 20-25 ml.

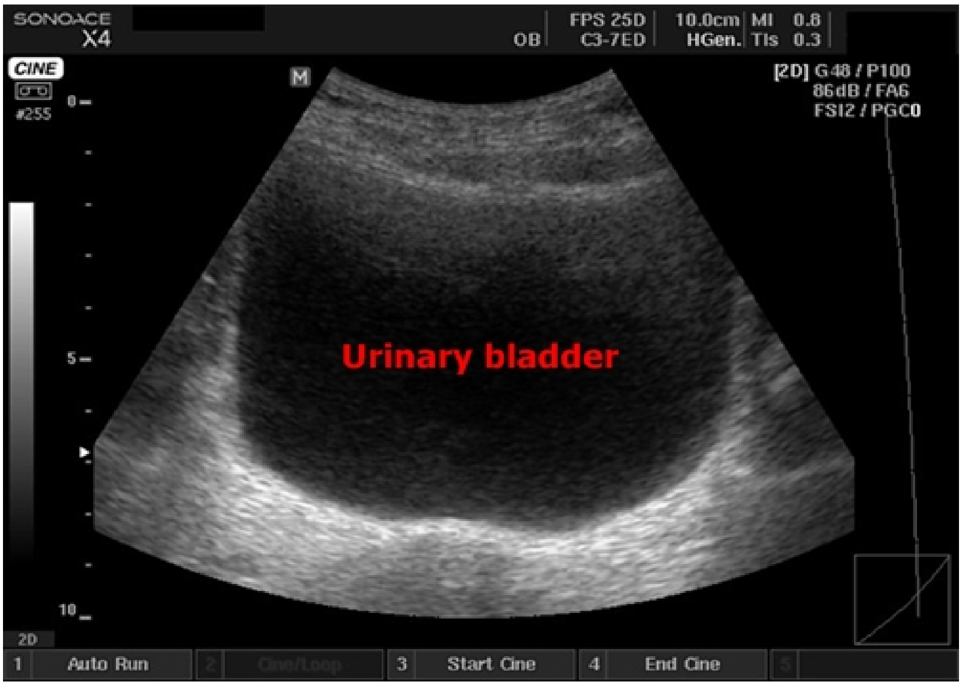
The seminal vesicles appear as paired lobulated echo-poor structures which often contain multiple small echo-free areas.

The testis consists almost entirely of seminiferous tubules enclosed by the fibrous tunica albuginea that extends as septations between lobules of testicular parenchyma, dividing the testis into several hundred lobules. These septations cannot be imaged except where they converge at the mediastinum testis to produce a linear structure that is reflective on US. The seminiferous tubules merge centrally to form the rete testis, from which efferent tubules perforate the tunica albuginea and convey seminal fluid to the epididymis. The adult testis is 3–5 cm in length and 2–3 cm in transverse diameter and depth. The normal adult testicular volume is 15–20 ml calculated from the formula: length × width × depth × 0.52 = volume. The testis has homogeneous medium level echoes throughout. Coronal scans show the mediastinum as a line of high echogenicity posteriorly.

At the upper pole is a remnant of the Mullerian duct, the appendix of the testis or hydatid of Morgagni, a 3–5 mm appendage of similar reflectivity to the testis. A further appendage, the appendix of the epididymis is situated at the upper pole of the testis. The epididymis usually lies posterior to the testis but may be seen on US laterally or anterior to the testis. The epididymis comprises a head, tail and body. The head lies adjacent to the superior pole of the testis. The body is formed from the confluence of the ductules of the rete testis to form a single ducts epididymis; this continues as the tail of the epididymis at the inferior aspect of the testis. At the tail of the epididymis, the duct courses cephalad to form the vas deferens.



normal renal ultrasound



Advantages

- a kidney ultrasound is a noninvasive diagnostic exam
- safety and low cost

- generally no discomfort from the application of the ultrasound transducer to the skin
- evaluation size and shape of kidney
- evaluation their position
- the procedure of choice for evaluation polycystic kidney disease
- detection renal masses
- detection congenital anomalies of renal system
- detection abscess, obstructions, fluid collection, and infection within or around the kidneys
- signs of injury to the kidneys, ureters and urinary bladder
- detection calculi of the kidneys and ureters
- may be performed to assist in placement of needles used to biopsy the kidneys, to drain fluid from a cyst or abscess, or to place a drainage tube
- indication of the residual volume
- measure of bladder function
- assess blood flow to the kidneys
- evaluation the transplanted kidney

Limitations of renal ultrasonography are as follows:

- interpretation is operator-dependent
- large body habitus renders the interpretation difficult
- barium within the intestines from a recent barium procedure
- intestinal gas

2. Duplex US (dopplerography)

Indications

- diagnosis of urinary obstruction independently of the kidney function, differential diagnosis of obstructing and functional dilatation of PCS after the value of the vascular resistance
- diagnosis of doubling a kidney due to visualization of two vascular pedicles

- evaluation of the degree of vascularization of voluminous formations of the urinary system
- evaluation of a renal transplantant
- diagnosis of stenosis, occlusions, thrombosis of renal vessels
- choice of a “blood – free” zone in invasive interventions under the control of US

Preparation

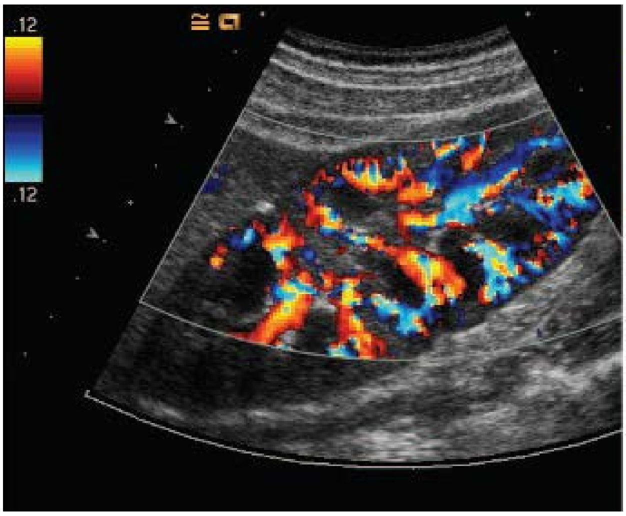
There is little preparation required for duplex ultrasound. Occasionally, patients may need to fast before an abdominal exam.

Procedure

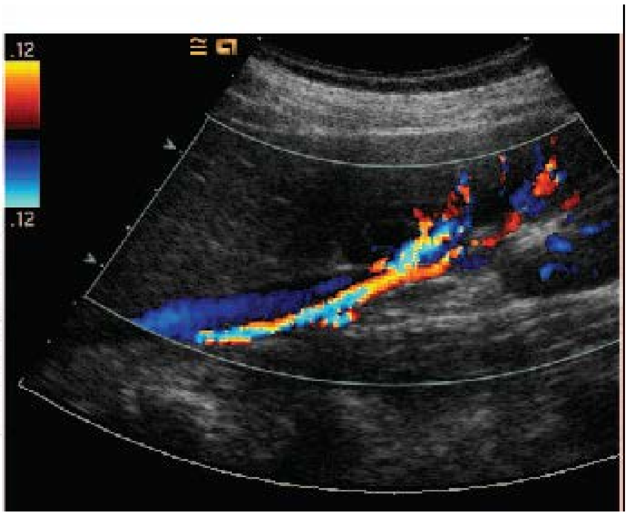
The vascular tree of the kidney can be effectively demonstrated with colour Doppler. By manipulating the system sensitivity and using a low pulse repetition frequency (PRF), small vessels can be demonstrated at the periphery of the kidney.

Demonstration of the extrarenal main artery and vein with colour Doppler is most successful in the coronal or axial section by identifying the renal hilum and tracing the artery back to the aorta or the vein to the inferior vena cava (IVC). The best Doppler signals, that is, the highest Doppler shift frequencies, are obtained when the direction of the vessel is parallel to the beam, and taken on suspended respiration. The left renal vein is readily demonstrated between the superior mesenteric artery (SMA) and aorta by scanning just below the body of the pancreas in transverse section. The origins of the renal arteries may be seen arising from the aorta in a coronal section.

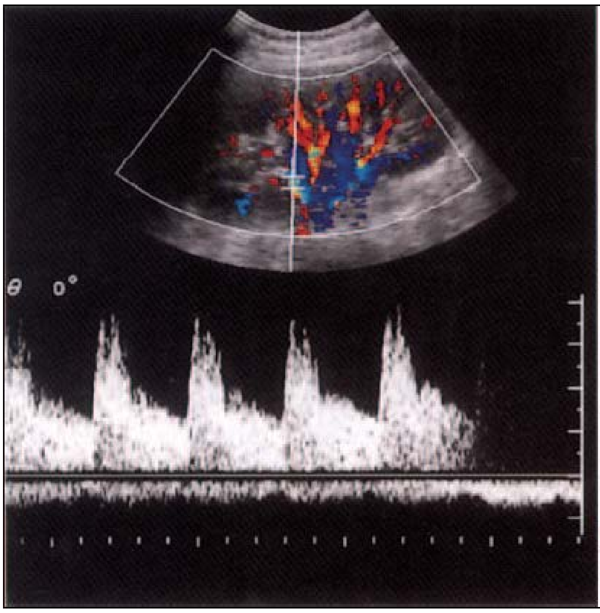
The normal adult renal vasculature is of low resistance with a fast, almost vertical systolic upstroke and continuous forward end diastolic low. Resistance generally increases with age. The more peripheral arteries are of lower velocity with weaker Doppler signals, and are less pulsate than the main vessel.

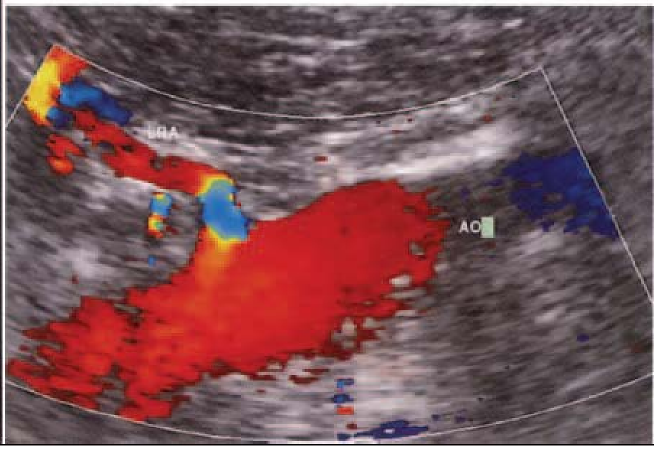


colour Doppler of the RK in coronal section demonstrates normal global intrarenal perfusion throughout the kidney



TS through the LK demonstrates the main renal vein (blue) draining into the IVC. The main renal artery can be seen in red alongside.





Advantages

The main advantages of this technique are:

- include a lack of radiation and lack of contrast agents
- for people who are claustrophobic, this technique has another advantage of avoiding the MRI machine
- exact and quick stone localization
- minimal loss of renal function owing to preservation of the intrarenal vascular system

- no need for renal ischemia and cooling
- morphologic appreciation of atherosclerotic changes in the renal artery wall
- visualization of a narrowed lumen with markedly reduced flow that may help differentiate subocclusive renal artery stenosis from occlusion
- increased confidence in the diagnosis of renal vein thrombosis and in the assessment of caval tumor thrombus
- better appreciation of renal cortical perfusion defects

Disadvantages

- renal artery ultrasound is difficult in patients who have a short stature
- some anatomical structures are difficult to differentiate with renal artery ultrasound
- renal artery ultrasound can miss findings outside the blood vessels
- obesity and bowel gas are major limitations in renal artery ultrasound

3. Plain film

A plain abdominal film is essential prior to urinary tract investigation.

Plain x-ray (scout film)

It gives information about:

- renal outlines
- psoas muscles
- bony structures such as vertebra and its appendages, pelvis
- any stones
- abdominal mass
- foreign body

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.

As stated, 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.

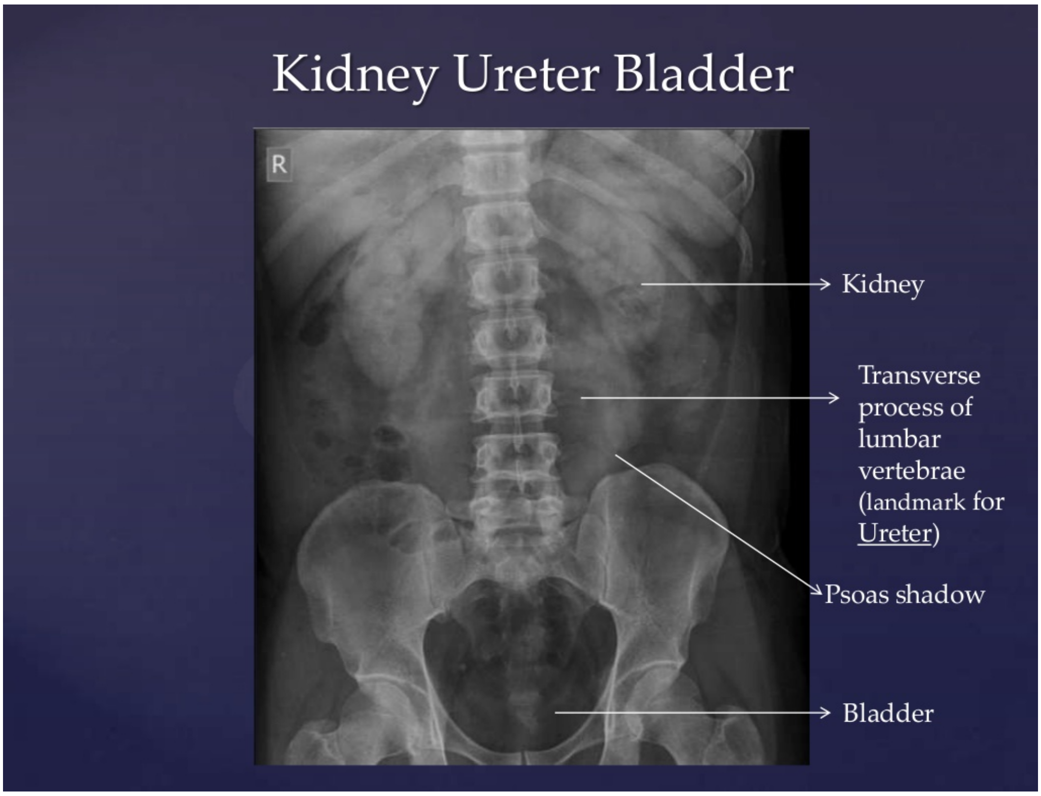
Soft tissue masses can occasionally be detected and suggest renal or pelvic lesions. Sclerotic bony lesions can suggest metastatic prostate cancer and lytic bony lesions can be seen with disseminated renal cell carcinoma. Additionally, the bony changes of renal osteodystrophy (diffuse bony sclerosis) may be identified on plain radiographs. Vertebral anomalies are associated with congenital malformations of the urinary tract.

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.

Finally, radiographs are useful for detecting and evaluating urinary tract calculi. 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.

plain abdominal film (supine position)



plain abdominal film

Additionally, the specificity of conventional radiography is somewhat limited because a multitude of other calcifications occurs in the abdomen, including arterial vascular calcifications, pancreatic calcifications, gallstones, leiomyomas, and many more. Phleboliths, which are calcified venous thrombosis, 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.

Normal calcification

- costal cartilage
- mesenteric lymph nodes
- pelvic vein phleboliths

Abnormal calcification

Calcium indicates pathology in:

- pancreas
- renal parenchymal tissue
- blood vessels and vascular aneurysms
- gallbladder fibroids (leiomyoma)
- uterine fibroid

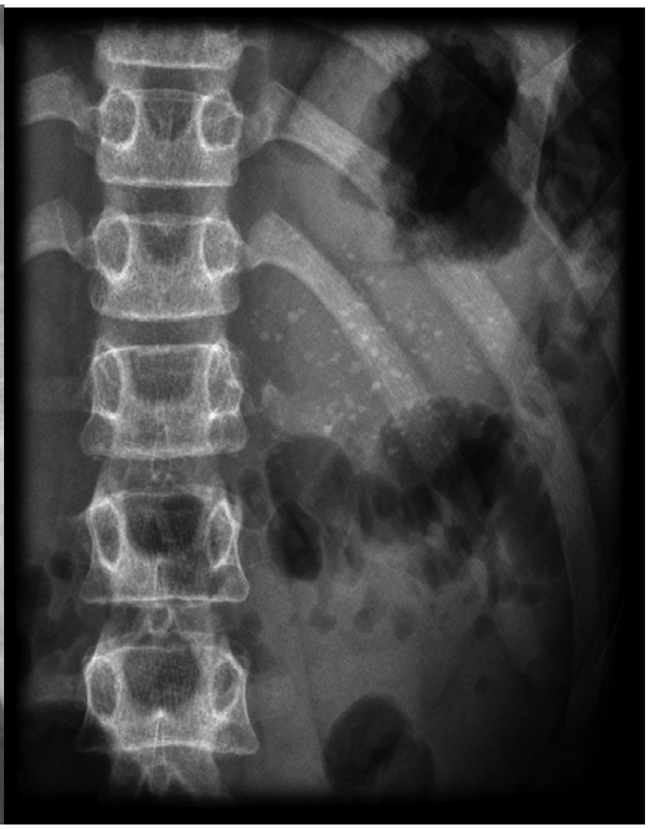
Calcium can make the following pathology visible:

- biliary calculi
- renal calculi
- prostate gland
- appendicolith
- bladder calculi
- teratoma

calcification of costal cartilage

calcification of mesenteric lymph nodes

calcification of pelvic vein phleboliths



pancreatic calcifications

nephrocalcinosis: calcium salt deposits in the renal parenchyma

abdominal x –ray with evidence calcified edge of the abdominal aortic aneurism

calcified uterine fibroid

gallstones

abdominal x-ray showing a calculus in the right kidney.

prostate gland calcifications

appendicolith

bladder calculi

teratoma x-ray

Preparation

Bowel preparation to the kidney radiography and intravenous urography is routinely administered in many radiologic centers to improve the image quality and visibility of the urinary tract details.

Fluid and food restriction and bowel preparation have been considered to reduce overlying bowel gas and feces that may obscure details on the images.

Functional constipation may also increase bowel gas and fecal residue and impair the quality of images.

Procedure

Plain film is taken in supine position. The radiograph should include the upper poles of both the kidneys and lower border of symphysis pubis (for prostatic urethra).

Advantages

- abdominal x-ray imaging is a painless, minimally invasive procedure with rare complications
- radiology examinations can often provide enough information to avoid more invasive procedures
- x-ray equipment is relatively inexpensive
- abdominal x-ray imaging is fast and easy

- no radiation remains in a patient's body after an x-ray examination
- it's have no side effects in the typical diagnostic range for this exam
- may be used to help diagnose unexplained pain, nausea or vomiting
- abdominal x-ray may also be used to help properly place catheters and tubes used for feeding or to decompress organs such as the kidneys

Disadvantages

- It is difficult to distinguish vascular calcifications from ureteral calcifications with plain radiography
- plain films are not sensitive enough to exclude tumors of the kidney or urothelial tract
- this imaging technique does provide general information regarding kidney size and shape

4. Intravenous urography IVU

The IVU consists of a series of plain films taken after administration of an intravenous injection of a water-soluble iodine containing contrast medium.

Indications

1. Obstructive calculi
2. Haematuria or pyuria
3. Diseases of renal collecting system and renal pelvis
4. Abnormalities of the ureter
5. Tuberculosis of the urinary tract
6. Prior to endourological procedures and surgery of the urinary tract
7. Suspected renal injury
8. Renal colic or flank pain
9. In children- polycystic kidney diseases, pelvi-ureteric junction obstruction, anorectal anomalies
10. Pelvic malignancies to see uretic involvement

Traditionally the patient was prepared with a period of 4 h starvation and fluid deprivation and the bowel purged with a strong laxative. Occasionally the patient will feel nauseated after the IVU injection and rarely there will be a severe reaction with the need for cardiovascular and occasionally cardiopulmonary support. With this in mind, it seems reasonable to persist with avoidance of food for 2-4 h prior to the procedure.

Radiological anatomy

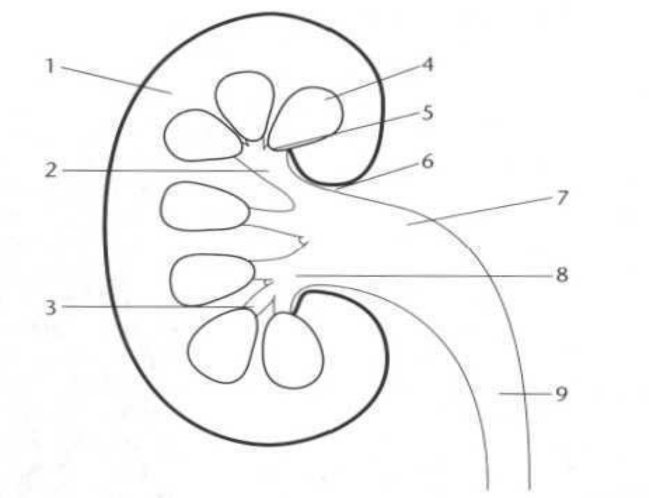
The kidneys are typically located at the level of the upper lumbar spine with the right kidney slightly lower than the left. They generally lie with their axes along the psoas muscles with the upper pole slightly more medial than the lower. Alterations in position and orientation of the kidneys may be related to congenital anomalies such as pelvic kidneys or may be secondary to mass effect from an adjacent lesion.

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.

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).

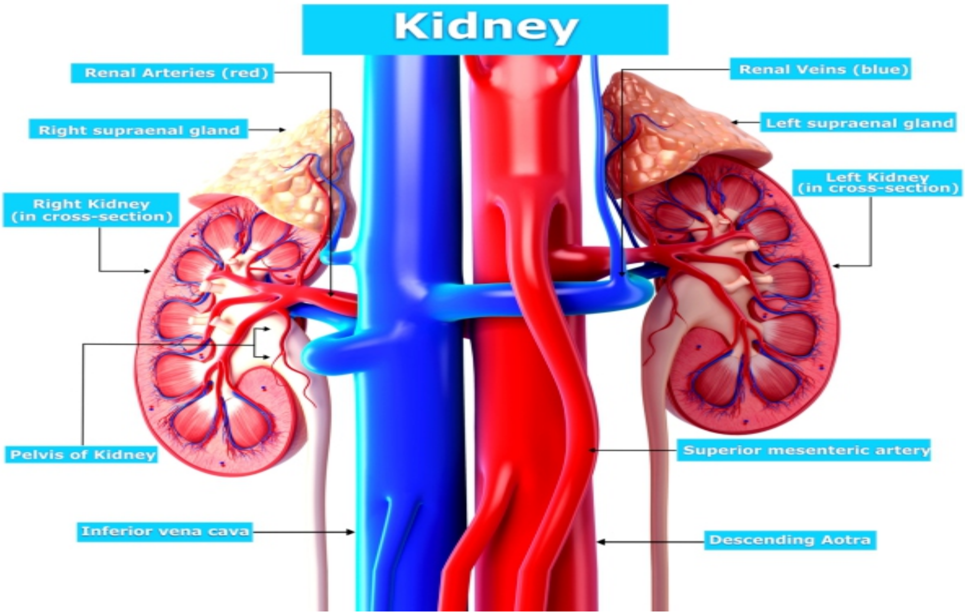
The kidneys should have a reniform shape and a smooth contour.

The intrarenal collecting system consists of calyces, infundibula, and the renal pelvis. Normally, each kidney consists of 7 to 14 evenly distributed calyces.



structure of the kidney:

1. cortex; 2. compound calyx; 3, minor calyx; 4. medullary pyramid; 5. papilla; 6. renal sinus; 7. renal pelvis; 8. infundibulum of major calyx; 9. ureter.



The normal ureters exhibit continual peristalsis and on a single film, it is uncommon to demonstrate the entire length of both (or even either) ureters.

They will often demonstrate smoothly narrowed areas (especially at the pelviureteric junctions and as they cross the iliac vessels in the pelvis) and more relaxed capacious areas. This is normal. 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 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. 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.

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.

Patient preparation

- blood urea and serum creatinine level should be within normal limits
- if patient is asthmatic premedication in the form of steroids is administered two days prior
- fasting after 10 pm (previous night) (as contrast injection sometimes induces nausea which might lead to vomiting and aspiration)
- patient should be well hydrated (dehydrated patients are prone for renal damage)
- bowel preparation is necessary, as gas and fecal matter filled bowel loops will obscure the kidney shadows
- low residue diet with plenty of oral fluids, the day previous to the IVU

Contrast media

Contrast materials currently in use are excreted almost exclusively by glomerular filtration, with subsequent concentration in the renal tubules and progressive opacification of the urinary tract.

They are two types:

1. ionic (urograffin, angiograffin)
2. non-ionic(omnipaque, ultravist)

Ionic contrast media have a higher incidence of reaction but they are cheaper as compared to the non-ionic contrast media.

Procedure

Patient is placed in supine position. The patient is asked to void the bladder before the procedure.

Contrast media is injected intravenously into a prominent vein in the arm. Test injection of 1ml of contrast is given and patient observed for 5 min for any contrast reactions. Then the rest of the contrast is rapidly injected within 30-60 seconds.

The dose of contrast media is 2 ml/kg body wt.

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. Capturing this sequential "opacification" on radiographs is the fundamental basis of the IVU. There are many variations in the filming sequence for the urogram that are acceptable as long as it optimizes visualization of specific anatomy of the urinary tract during maximum contrast opacification. Optimal visualization of the kidney is accomplished very early in the examination. 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*.**

The kidneys should be evaluated for:

- their position
- orientation
- size
- contour
- radiographic density.

Soon after the nephrographic phase, contrast begins filling the intrarenal collecting system including the calyces and renal pelvis. This portion of the study is termed the ***pyelographic phase***.

5-10 min film

Shows nephrogram, renal pelvis

15-20 min film

A complete visualization of the pelvicalyceal system entire ureters is possible in this film, especially with the patient in prone position as the ureters will be antedependent in prone position.

30-35 min film

A complete visualization of the urinary tract: kidney, ureter, bladder can be done and bladder distension can be evaluated in the later film.

The series is varied according to the individual patient. Renal obstruction may require a delayed study up to 24 hours to outline the pelvicalyceal system.

intravenous urography IVU (normal)

Advantages

- IVU is low cost
- anesthesia is not needed
- detailed anatomy of the collecting system

- rapid overview of the entire urinary tract
- demonstration of calcifications
- demonstrate renal function and allow for verification that the opposite kidney is functioning normally
- it is sensitive for obstruction
- can show non opaque stones as filling defect
- IVP is an excellent modality to diagnose medullary sponge kidney and papillary necrosis

Disadvantages

- contrast material must be avoided in patients with a history of allergy, hay fever or asthma until steroid cover has been given; those on metformin must stop this drug for 24 h before any contrast. These groups cannot safely undergo an emergency IVU.
- the differentiation from a phlebolith is difficult, especially when there is no ureteric dilatation proximally
- contraindications renal insufficiency
- contraindications hepatorenal syndrome, thyrotoxicosis, pregnancy
- do not differentiate solid or cystic lesion
- requires contrast medium and radiation
- missing small stones
- quality of study may be limited by inadequate bowel preparation
- inconvenience of a long filming sequence

Retrograde and antegrade pyelography

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.

5. Retrograde pyelography

Indications

This investigation aims to optimally opacify the pelvicalyceal system and ureter. It usually follows an IVU and is indicated when there is persistent uncertainty about the diagnosis, particularly if there is haematuria and suspicious cytology. It is indicated to confirm or refute the presence of one or more filling defects within the collecting system, or to improve demonstration of the collecting system, when there has been inadequate demonstration of part or all of the system or when the IVU is normal but the abnormal laboratory findings persist. It is occasionally used to demonstrate the lower end of an obstructed ureter.

Patient preparation

Laxatives or enemas may be necessary before the procedure, as the bowel must be relatively empty to provide visualization of the urinary tract.

Procedure

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 CT urography, 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.

The retrograde pyelogram was once used as a method of clearly defining the anatomy of the renal drainage system in the patient with a non-functioning kidney or with a poorly functioning kidney when intravenous pyelography had failed to provide adequate visualisation.

Retrograde pyelography is still sometimes used to confirm or disprove the relationship of a suspected small calculus to the ureter.

Advantages

- retrograde pyelography is an essential tool for localizing the site of urinary tract obstruction
- it may also prove therapeutic (eg, ureteral stents can be placed to relieve an obstruction).

Disadvantages

Possible complications of retrograde pyelogram include:

- urinary tract infection
- bladder tear
- bleeding and injury to the ureter
- nausea or vomiting

normal retrograde pyelography.

6. Antegrade pyelography

This is a relatively simple procedure.

Indications

Percutaneous antegrade pyelography is a useful method of demonstrating the renal calyces, pelvis and ureter in cases of suspected urinary tract obstruction where the intravenous method has been unsuccessful or inconclusive. Unlike retrograde pyelography, it does not require general anaesthetic and it has a lower incidence of urinary tract infection. It is also useful in infants and children where cystoscopy is difficult or impossible.

Generally, no preparation is necessary prior to this test.

Patient preparation

Laxatives or enemas may be necessary before the procedure, as the bowel must be relatively empty to provide visualization of the urinary tract.

Procedure

A dilated renal calyx is punctured percutaneously from the lumbar region using a fine needle, and contrast medium is injected. The technique can also be used to insert a catheter and provide temporary drainage. The catheter tract can also be used for a percutaneous approach to renal calculi and for stent insertion.

Advantages

- this procedure can be used to relieve obstruction by insertion of a nephrostomy tube
- there is relatively low radiation exposure during this test

Disadvantages

Possible complications of antegrade pyelogram include:

- bleeding
- infection
- formation of a urine-filled cyst (urinoma)
- blood clots in the nephrostomy tube if used, or clots in the bladder

antegrade pyelography

7. Cystography

Imaging of the bladder is performed with a cystogram.

Indications

- the extent of vesicoureteral reflux
- urinary stress incontinence can be assessed
- urinary tract infections
- suspected obstruction
- suspected bladder trauma or rupture
- detection tumor
- detection diverticula
- detection stones
- to investigate suspected fistulas involving the bladder (usually into the gastrointestinal tract, occasionally elsewhere such as the vagina)

Procedure

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.

The method is useful for outlining tumors of the bladder when intravenous urography has been unsuccessful or equivocal.

One advantage to cystography is that vesicoureteral reflux can be evaluated during the conventional cystogram unlike during IVU.

Cystography can be classified into three groups:

- micturiting cystourethrography (MCUG)
- dynamic cystography
- simple cystography.

The MCUG is primarily performed for an investigation of childhood.

Dynamic cystography is part of the urodynamics investigation of the lower urinary tract.

Simple cystography is a relatively frequently performed and straightforward investigation in the adult.

normal cystography

Patient preparation

For two days before the examination, medical experts recommend limiting intake of products that provoke flatulence. On the eve of the research (in the evening), as well as immediately before cystography (morning) held enema.

Advantages

- these imaging tests provide the basic anatomy of the bladder and urethra
- show urethral movement
- low cost
- wide availability
- general familiarity

Disadvantages

- cystography is contraindicated spend in acute inflammation of the bladder, urethra, scrotum, prostate and seminal vesicles (If the research is still necessary, the doctor can perform a downward cystography)
- the catheter could damage the urethra, bladder or nearby structures
- they require catheterization
- the images contain no information about the pelvic musculature and adjacent soft tissue structures
- only structures in direct contact with the urethral and bladder lumen opacify with contrast

8. Urethrocystography

This can be performed via ***an ascending*** or ***descending*** approach.

Descending urethrocystography

Indications

- it allows both an exploration of the morphology and dynamics of the bladder, urethra and ureter junction bladder
- the urethrocystography is mainly indicated in the assessment of voiding dysfunction in adults, and urinary incontinence in children and infants to recurrent urinary tract infections

Procedure

When it is performed in adults the bladder should be adequately filled (with at least 200 ml of 150 strength contrast). The screening table should be positioned erect. Imaging is performed directly anteroposterior in females and in a 45° oblique projection in males.

Males are generally used to micturating while standing, often in unusual situations, and can manage with a bottle while screening is performed and spot films taken of the urethra and bladder base.

Females are provided with a special drainage receptacle that is held between the thighs.

Ascending urethrography is essentially confined to the male.

It is used:

1. in the investigation of trauma,
2. stricture
3. filling defects
4. masses
5. and fistulas

Procedure

The patient is positioned in a 45° oblique position with the dependent hip partly flexed to provide stability and ensure the urethra is not projected over hone. A I2-16 gauge Foley catheter is positioned with its balloon a Couple of centimeters into the distal urethra. The balloon is gently partially inflated to provide a seal without undue trauma. Between 5 and 10 nil 150 strength contrast is injected gently into the urethra under direct screening and spot filets arc taken. The urethra is usually easily opacifed hack to the urogenital diaphragm. In a minority of patients contrast will reflux into the posterior urethra and bladder. Usually, however, with ascending urethrography the prostatic urethra is not demonstrated.

Female urethrography is rarely required, virtually all urethral pathology being better demonstrated on urethroscopy or trailsvaginal sonography.

Radiological anatomy

The male urethra

The male urethra extends from the bladder neck to the external urethral meatus (~20 cm), passing through the body of the prostate gland, the urogenital diaphragm and the penis.

The male urethra is approximately 20 cm long and is divided into posterior (prostatic and membranous) and anterior (spongy) parts. The posterior urethra is 4 cm long and the anterior approximately 16 cm.

The prostatic urethra is 3 cm long. It is the widest part of the urethra. On its posterior wall is a ridge, the urethral or prostatic crest. In the middle of the crest is a further prominence, the verumontanum. On either side of this, the ejaculatory ducts open.

The membranous urethra, 1.5 cm long, runs through the external urethral sphincter within the urogenital diaphragm. This is the narrowest, most fixed part of the urethra and is therefore most prone to injury.

The spongy urethra is further subdivided into the bulbous and penile urethra. It is surrounded by the corpus spongiosum. The long penile urethra is relatively narrow apart from a dilatation within the glans penis, the navicular fossa. The external urethral orifice is narrow and calculi may lodge at this site.

The female urethra

This is 3–4 cm in length and extends from the neck of the bladder to the vestibule, where it opens 2.5 cm behind the clitoris.

normal voiding cystourethrogram

Patient preparation

There is no specific preparation for a urethrogram examination.

Advantages

- the method gives a clear picture of any changes in the bladder, whether these be of an organic or functional nature
- the micturition films also give important information regarding the urethra such as its course and degree of dilatation
- presence of the formation of valves, strictures, diverticula, etc
- x-rays usually have no side effects in the typical diagnostic range for this exam.

Disadvantages

- they do not give sufficient information about the mucosal pattern of the urethra - especially in its distal portion
- this investigation involves exposure to x-rays
- the contrast dye that is used contains iodine which some people are allergic to
- some children experience discomfort during urination immediately after the procedure; this discomfort usually resolves in less than 12 hours

9. *Computed Tomography*

Multidetector (spiral) CT (MSCT) is now the dominant radiologic imaging modality for evaluation of the urinary tract and adrenal glands. Several factors make CT quite effective. The high contrast and spatial resolution afforded by CT allow detection and evaluation of subtle differences in very small structures. Examinations can be performed quickly and reproducibly with thin CT slices of the entire urinary tract now obtainable in just a few seconds.

With these advances, CT can now be used to evaluate much of the urinary tract, including vascular, parenchymal, and urothelial components as well as adjacent structures including the adrenal glands.

It is used*:*

- in the characterization of renal masses
- staging of urinary tract tumours
- in the assessment of inflammatory processes
- in the assessment of traumatic processes
- detection calculi
- detection the causes of obstruction
- to direct biopsies and the positioning of percutaneous drains
- to assess renal artery stenosis
- for the detection of ureteric leaks or fistulae
- for investigation of living related donors before renal transplantation

Patient preparation

Patients with diabetes cannot take drugs containing Metformin (Glucophage, Glucovance, Metaglip, Actoplus, Prandimet, Kombiglyze, Janumet, Avandamet, Fortamet, and Riomet) on the day of the study and within 48 hours after.

Patients with allergies in the history of the disease recommends the following premedications:

- Take 30 mg prednisolone on the night before the scan.
- Another 30 mg prednisolone on the morning of the scan.

The patient should have nothing to eat or drink for a minimum of 3 hours prior to exam. The patient should drink 16 ounces of water 1 hour prior to the exam.
Non-IV Contrast examinations do not require special preparation.

Creatinine/eGFR is to be obtained for patients at risk for reduced renal function including the following:

- age 60 years and older
- history of multiple myeloma
- history of renal disease, renal transplantation, renal carcinoma, renal nephrectomy
- history of liver transplantation, hepato-renal syndrome
- history of sickle cell anemia

- diabetes
- history of hypertension requiring medical therapy

Creatinine needs to be drawn within 30 days of the exam date.

Procedure

Careful techniques and protocols are critical to CT accuracy. CT scans of the urinary tract may be performed with and/or without intravenous iodinated contrast material depending on the indications. CT performed without contrast is typically used for the detection of renal or ureteral calculi, for which it is exquisitely sensitive.

Additionally, noncontrast views of the kidneys serve as a baseline to evaluate for lesion enhancement after contrast administration, a critical factor in mass evaluation.

Intravenously administered iodinated contrast is excreted by the kidney primarily by glomerular filtration, opacifying the urinary tract progressively from the kidney through the ureter and to the bladder. Contrast "opacification" during CT is most accurate, exquisitely demonstrating and evaluating the urinary tract.

CTU is most often indicated for evaluation of hematuria and typically consists of three scanning phases:

- noncontrast
- nephrographic (90 seconds)
- delayed (8 to 10 minutes) excretory phase

The noncontrast phase allows for stone detection and serves as a baseline to assess possible mass enhancement. The kidneys are homogeneous and have a density similar to most soft tissue.

The nephrographic phase is predominately used to evaluate the kidneys for mass lesions.

The excretory phase allows assessment of the collecting system, particularly for the detection of urothelial carcinoma.

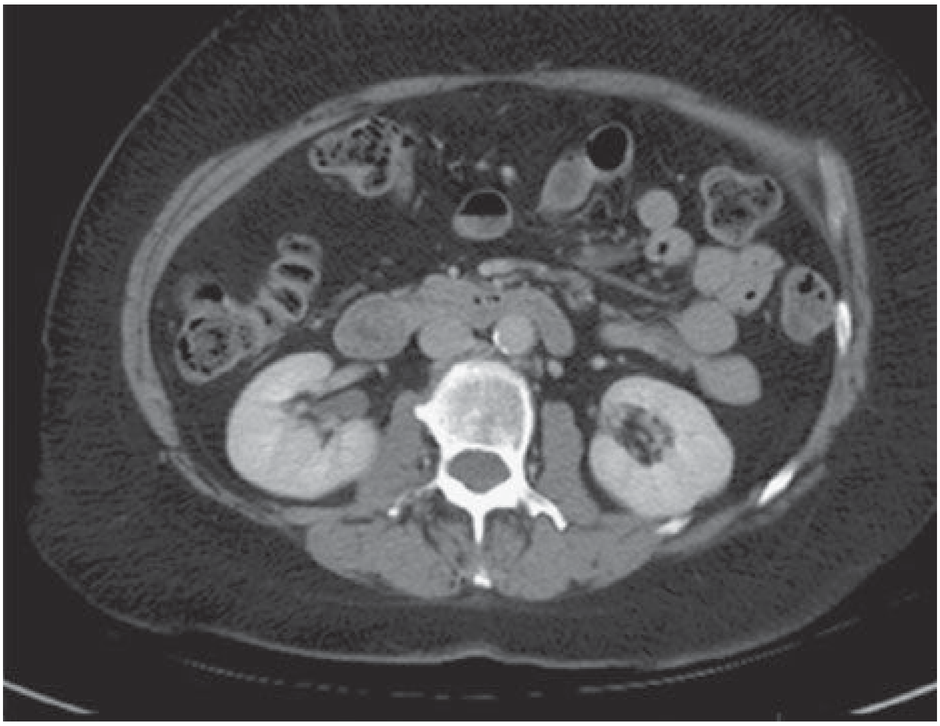
Frequently, the axial CT images are augmented with multiplanar and three-dimensional reconstructions.

With rapid scanning after contrast administration, several sequential phases of opacification within the kidney can be delineated by CT including the:

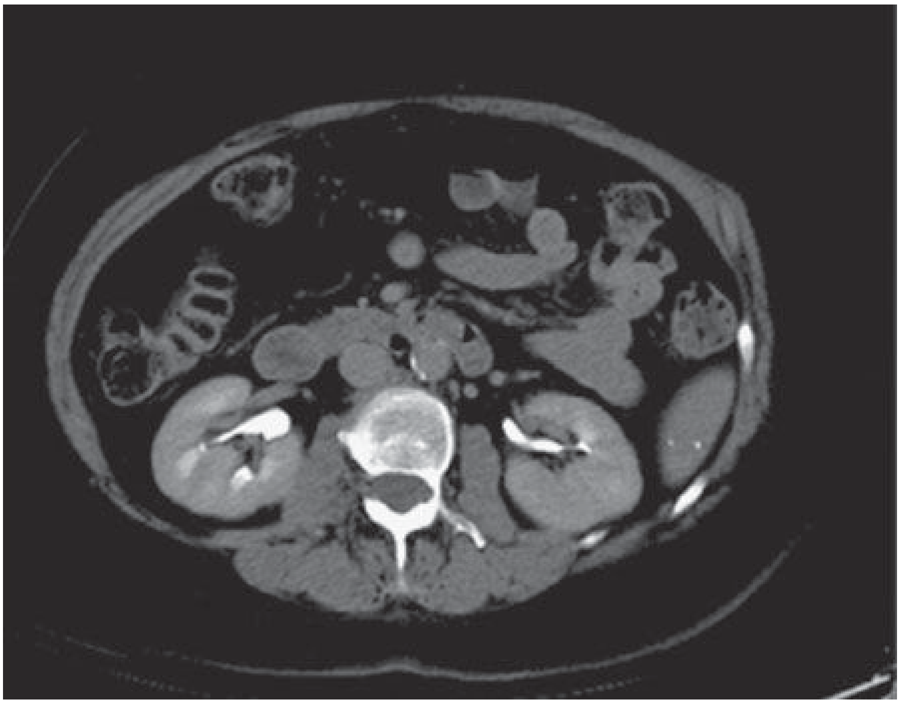
- corticomedullary
- nephrographic
- excretory phases

The corticomedullary phase can be seen if scanning is performed during the first 20 to 70 seconds after contrast administration and represents the early preferential blood flow to the renal cortex. 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 90 to 120 seconds 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 clinical indication.

noncontrast



nephrographic phase



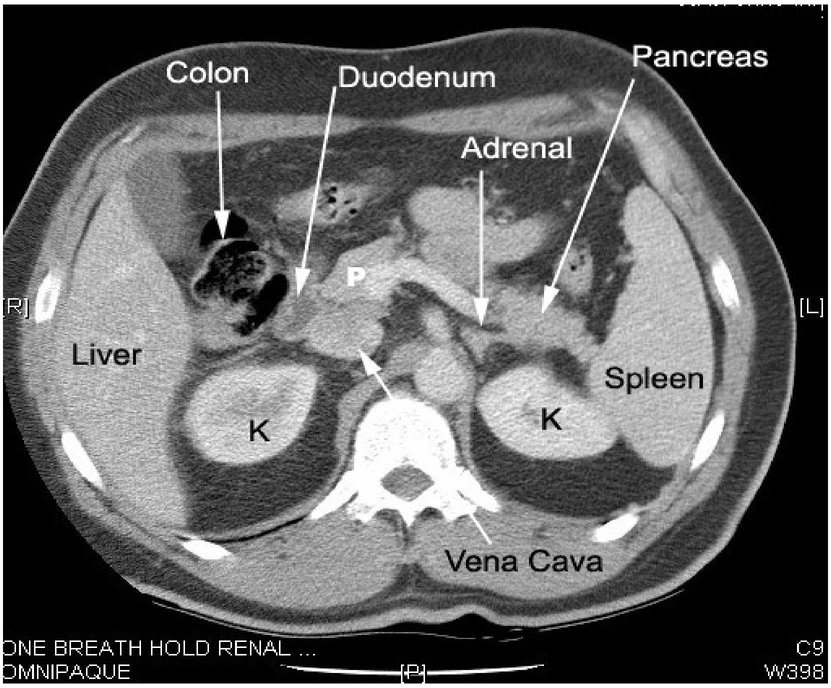
excretory phase

three-dimensional reconstructions

On CT, the kidneys should be evaluated for size, location, orientation, and contour.

There are a number of causes of abnormal renal size, ranging from incidental anomalies such as congenital renal hypoplasia to clinically 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 should be evaluated for calcifications, hydronephrosis, and inflammation. A critical role for CT is mass/cyst detection and characterization. CT is very specific in identifying a lesion as a simple cyst when the lesion is homogenous and of water density, typically -10 HU. Lesions of higher density may represent hyperdense (complex) cysts or solid masses, and further evaluation with contrast CT to detect enhancement may be needed to differentiate these causes.



normal anatomy kidney

Advantages

- CT scanning is painless, noninvasive and accurate
- CT examinations are fast and simple
- CT scan is an excellent tool to evaluate masses, traumatic injury to the kidney, stones, and pyelonephritis
- noncontrast helical CT scanning is the procedure of choice to evaluate kidney stones
- CT scanning is also used to differentiate malignant from nonmalignant renal masses
- moreover, CT scanning is essential to evaluate the local spread of a renal malignancy
- high sensitivity and specificity in diagnosing bladder pathology
- may further help define perivesical invasion and involvement
- may help guide treatment
- high-resolution CT angiography is excellent in defining the anatomy of the renal arteries and veins (eg, renal vein thrombosis)

- CT scanning is superior to ultrasonography in identifying renal cysts, since it is capable of detecting small cysts (2-3 mm in diameter)
- a CT scan, however, can be performed within just a few minutes, whereas delayed films are often required with an IVU
- CT is less sensitive to patient movement than MRI
- CT imaging provides real-time imaging, making it a good tool for guiding minimally invasive procedures such as needle
- a diagnosis determined by CT scanning may eliminate the need for exploratory surgery and surgical biopsy
- no radiation remains in a patient's body after a CT examination
- x-rays used in CT scans should have no immediate side effects

Disadvantages

- the primary limitation of CT scanning is the risk of radiation and administration of contrast
- contrast should be avoided if the patient is allergic, has renal failure, or is pregnant
- CT scanning has a higher radiation dose than plain x-ray

10. Magnetic resonance imaging (MRI)

Indications

- detailed assessment of the kidney anatomy
- noninvasive assessment of kidney function
- estimated glomerular filtration rate (GFR)
- assessment of congenital anomalies of the kidney, bladder, and urinary tract
- detection intraluminal neoplasia
- assessing size of lesions
- assessing adenopathy and involvement of other pelvic structures
- evidence of obstructed urinary tracts
- staging of malignant disease
- assessment of the viability of kidneys after transplantation

- assessment of renal injury in trauma

In children:

- MR urography can be used in the preoperative anatomic assessment of vascular anatomy
- in the evaluation of duplicated collecting systems
- in the evaluation renal dysplasia, ectopic ureter, retrocaval ureter, and primary megaureter
- distinguish hydronephrosis from cystic renal disease

Principle

The MRI urography requires neither ionizing radiation no iodinated contrast medium, and is capable of producing an image of the entire urinary tract in one imaging session.

Human tissues contain vast numbers of positively charged particles, many of which exist as hydrogen ions (otherwise known as protons) present in the body water. These protons are spinning and under normal conditions they all spin in different, random directions. Because of their positive charge they can act like tiny bar-magnets. If a patient is placed between the poles of a strong magnet, some of the protons will align along the axis of the applied magnetic field, i.e. along a straight line running from the north pole of the magnet to the south pole; the axis of the proton spin now lies along this line. The strength of a magnetic field is measured in Teslas (T) and typical field strengths used in imaging range from 0.15 to 1.5 T.

Once the patient is positioned within a magnetic field, allowing proton alignment, radio waves are applied. These radio waves affect a component of the protons' spin, altering the way in which some of them rotate. When the protons are displaced in this way, they gain energy. When the radio waves are switched off, the protons return to spinning normally within the magnetic field, as described above. This results in a release of the energy previously gained. This 'switching on-and-off' of radio waves is termed a pulse and the return of protons to their resting state is called relaxation. Various patterns of radio waves can be applied, depending on which aspects of a tissue need to be imaged. For example a brief pulse may be applied, followed by a pause, followed by a longer pulse. Each different pattern is termed a pulse sequence. The rate of relaxation of a proton is different for one in fatty tissue compared with one in free water, which is different again from one in water bound to a surface. Therefore, different pulse sequences are used in different tissues to emphasize the effect of different proton relaxation times. An aerial known as a coil detects the energy that is released during relaxation and this energy is then converted to produce an image.

The energy liberated from a proton as it relaxes can be detected at various different stages on its journey back to its resting state. The type of image that is produced will differ depending on the point at which this energy is detected. T1-weighted images are produced mainly from the energy detected at one particular stage of relaxation and T2-weighted images use energy from a different stage of relaxation. The type of pulse sequence used is important and can be used to excite the protons so that when they relax, a large amount of energy is emitted at the point when the T1 image is detected, i.e. when the ‘T1 effect’ is maximal. This is termed ‘T1-weighting’. In general, T1-weighted images are good for showing the structure of organs and tissues, and water appears dark. T2-weighted images are used to highlight pathology and using this method, water appears as a bright signal.

Modifications of these principles are used to provide further images commonly used in current practice. Short tau inversion recovery (STIR) imaging uses a special technique, the physics of which are beyond the scope of this article, to suppress the signal produced from fat. This is often useful to delineate pathology shown on T2 images which may be obscured by the presence of fat, which also shows up brightly on T2 weightings. Extra sets of magnets (gradient magnets) are used to allow imaging in any plane. Images are most frequently produced in the axial, sagittal and coronal views, but any flat or curved surface can be imaged if required.

As mentioned, coils are used to detect liberated energy; many of these coils are designed to lie close to an area of interest. Signals from this area will be detected most clearly, allowing a high-resolution image. However, the field of view from a surface coil tends to be small. Therefore many examinations involve the use of body coils which can receive signal from a large volume of tissue. Endorectal coils are surface coils that are useful for examining the pelvis, particularly the prostate.

Contrast media

Contrast media in MRI are agents capable of interacting with the magnetic fields of the tissues being imaged. In so doing, they cause a reduction in relaxation time and an increase in T1 signal intensity, depending on the perfusion of the tissue. There are three main groups of substances capable of acting as contrast media: ferromagnetic, paramagnetic and superparamagnetic. The most commonly used contrast medium in urological imaging is gadolinium (dimeglumine gadopentate or Gd-DTPA). This is a paramagnetic substance which can be given intravenously and the main effect of which is to increase the signal intensity on T1-weighted images.

Patient preparation

No patient preparation is necessary prior to this test.

Procedure

The imaging protocol for evaluation of the kidney at our institution on a 1.5-Tesla (T) MRI system consists of the following sequences:

1. Coronal T2-weighted half Fourier single-shot turbo spin echo sequence (HASTE) (TR infinite, TE 120 ms, flip angle 90°, breath-hold), serving as a localizer, but also supplying valuable T2-weighted information. The limitation of this sequence is a relatively low signal-to-noise ratio.
2. Axial T2-weighted turbo spin echo sequence with fat suppression (TR 2,000 ms, TE 100 ms, flip angle 90°, respiratory triggering). This sequence provides for more detailed T2-weighted information. The T2-weighted sequence is especially helpful in characterizing cysts and intraparenchymal abscesses and in evaluating hydronephrosis. Furthermore, the T2-weighted sequence is helpful in detecting solid lesions.

3. Axial T1-weighted gradient echo sequence, in-phase and opposed-phase (TR 180 ms, TE 2.3 ms/4.6 ms, flip angle 90°, breath-hold), preferably as a dual-echo sequence. Many solid renal lesions are hypointense compared to the renal parenchyma on T1-weighted images, but lesions with hemorrhage, lesions with macroscopic fat, melanin-containing lesions and cysts with high protein content may show hyperintense signal. Opposed-phase T1-weighted gradient echo sequences can be used to prove the presence of small amounts of fat.
4. Axial T1-weighted gradient echo sequence for dynamic imaging (TR 130 ms, TE 1.0 ms, flip angle 90°), using 30 ml intravenous gadolinium contrast, immediately followed by three breath-hold periods with four scan series per breath-hold. In this way pre-contrast and post-contrast images in arterial and nephrographic phase are obtained. Gadolinium-enhanced images are used for lesion detection and characterization.
5. Coronal 3D fast gradient echo with fat suppression, obtained immediately after the dynamic series for delayed contrast-enhanced images (TR 3 ms, TE 2 ms, flip angle 15°). This sequence can be used for renal venous anatomy, for the analysis of (tumor) thrombus and for evaluation of extent of the tumor in the perinephric fat.

Currently 1- to 1.5-T systems are generally used for abdominal imaging, but the advent of 3-T MRI systems brings a twofold increase in the signal-to-noise ratio (SNR). The increase in SNR can be spent on higher resolution or on even faster imaging. When combined with parallel imaging techniques such as sensitivity encoding (SENSE), the speed of any sequence can be increased by up to a factor of four or higher. However, although 3-T MRI is promising, only a limited amount of research has been published on 3-T MR imaging for renal lesions, and its value has still to be established.

On MR imaging, the kidneys appear of variable signal intensity depending on the imaging factors, and as in CT, contrast-enhanced phases of imaging (arterial, corticomedullary, nephrographic, and excretory) are all visible.

Magnetic resonance angiography has proven useful in the evaluation of stenosis in the mid and proximal renal arteries

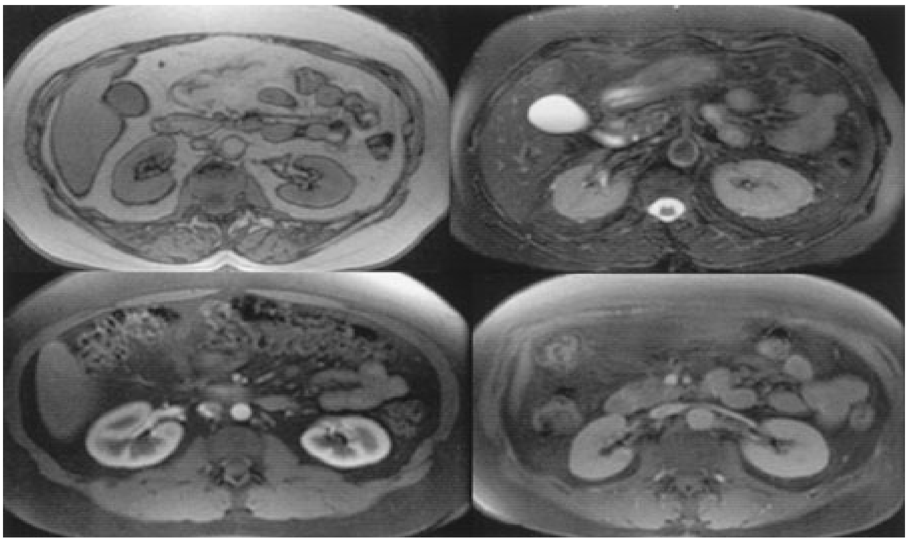
MRI anatomy

The normal anatomy of the kidney as seen on spin-echo sequences has been described. Using this method, fat has a short T1 value, consequently resulting in a high-intensity signal on the images. Therefore, the perirenal fat appears as a high-intensity area while the renal cortex is of lower intensity and the renal medulla lower still. A line of low signal intensity around the perirenal space indicates Gerota's fascia. The hilum of the kidney, with its blood vessels, also contains fat and gives an image of high signal intensity. Blood flow through these vessels produces a signal void and therefore they can be visualized within the hilum with no need for contrast medium.

The bladder is commonly imaged using sagittal and axial planes and a surface coil. This allows visualization of the bladder wall, the contents of the bladder, the extravesical fat and adjacent organs. The appearance of the normal bladder wall on MRI has been described as a single band of intermediate signal intensity on T1-weighted images, compared with T2-weighted images which show the wall to consist of two layers, the inner layer being of low and the outer layer being of intermediate signal intensity. Distinguishing these layers may not be possible if the bladder is trabeculated. These layers have been found to correlate with the inner and outer smooth muscle layers of the bladder on histopathological examination, the difference in signal intensities being caused by the density differences of the smooth muscle bundles in the different layers. The muscle layer between prostate and bladder can usually be visualized, although it is often very thin; in cases of BPH it may not be seen at all.

For normal anatomy, the prostate is best imaged in sagittal and coronal section, although transverse images also provide useful information. Both T1- and T2-weighted images are required to image the prostate fully, and STIR sequences may also assist in providing valuable information by suppressing the signal from fat. The normal prostate is homogenous with a medium-intensity signal on T1 weighting. It should be readily distinguished from adjacent structures such as the bladder base, rectum, fascia of Denonvillier and periprostatic fat. The seminal vesicles produce a similar signal to the prostate but are separate from the gland. Tumors of the seminal vesicle, such as the rare leiomyoma, have been described using endorectal coil imaging as a mass of low signal intensity arising from the seminal vesicle, not connected to the prostate or bladder. Endorectal coil imaging is required to visualize the true (anatomical) prostatic capsule, as this is too thin to be seen with body coil MRI.

On T1 weighting, BPH has a similar homogeneous medium-intensity signal to the normal gland, although the appearance on MRI can differ depending on the predominant constituents of the prostate. The appearances of four types of BPH on MRI have been described. The first is a type composed mainly of glandular tissue which tends to appear as nodules. When nodularity is present the prostate may have a heterogeneous appearance with higher signal intensity within the nodules. Second, BPH which is more fibromuscular produces a lower intensity signal without the heterogeneity of glandular tissue. BPH may also produce an enlarged prostate gland composed mainly of collagen and this produces lower signal intensity still. Finally, BPH made up of mixed elements of stroma and gland has a heterogeneous appearance. The glandular tissue produces an image of high signal intensity, whereas the stroma contrasts this with a low-intensity image.



normal MRI of the kidneys

The appearance of the kidneys is variable on MRI depending on imaging factors. The top left image is a T1-weighted sequence, and the top right is T2 weighted, whereas the bottom images were obtained after gadolinium injection and demonstrate corticomedullary and nephrographic phases.

Advantages

- MRI images can be obtained in any plane
- the images can be obtained relatively quickly
- it does not involve the use of ionizing radiation and there is no evidence to suggest that the procedure causes cellular toxicity
- magnetic resonance imaging (MRI) provides a useful alternative to CT scanning in individuals at risk for toxicity from intravenous contrast
- magnetic resonance angiography has proven useful in the evaluation of stenosis in the mid and proximal renal arteries
- magnetic resonance urography is commonly used in children and pregnant women to avoid the risk of ionizing radiation
- the contrast material used in MRI exams is less likely to produce an allergic reaction than the iodine-based contrast materials used for conventional x-rays and CT scanning.

Disadvantages

- the major limitation of MR urography is the limited sensitivity for calculi relative to CT
- this technique is limited to use in patients with distended urinary collecting systems
- it is also a relatively expensive procedure

the image may be subject to distortion by metal foreign bodies, causing the production of artefacts

People with the following implants cannot be scanned and should not enter the MRI scanning area:

- cochlear (ear) implant

- some types of clips used for brain aneurysms
- some types of metal coils placed within blood vessels
- nearly all cardiac defibrillators and pacemakers

- the longer time required to produce an image compared with other modalities and the claustrophobic effect which the scanning chamber may have, will make it unsuitable for some patients
- the risk of gadolinium contrast remains a significant concern in patients with renal insufficiency

11. Nuclear medicine

11.1 MAG3 renography

99mTc-MAG3(mercaptoacetyltriglycine) has become the agent of choice for dynamic radionuclide imaging of the renal tract in most centers. It was first developed as an alternative to hippuran, but has a plasma clearance 50–65% slower than that of hippuran. Nevertheless, it gives images comparable to 123I-hippuran. Following intravenous injection, it remains loosely bound to serum proteins, and only a small proportion undergoes glomerular flirtation. Clearance is predominantly by tubular secretion. The 30-minute excretion of 99mTc-MAG3 is approximately 70%, and by 3 hours 90% of the tracer is cleared by the kidneys. Renography can be combined with administration of a diuretic (usually frusemide) to produce a high urine flow diuresis renogram. The 99mTc-MAG3 is an adequate tool for the assessment of urinary uptake, transit, excretion, and split renal function. In addition, simple conversion methods will allow reproducible estimations of ERPF from the 99mTc-MAG3 activity curve.

Indications

- assessment of whole or relative kidney function

- before and after surgical intervention (e.g., pyeloplasty, partial/total nephrectomy)
- investigation of acute or chronic renal failure
- assessment of the transplanted kidney

- assessment of renal function following trauma
- assessment of kidney drainage in obstructive uropathy (e.g., uretero-pelvic junction obstruction, renal stones)
- assessment of congenital renal abnormalities (e.g., duplex, horseshoe, absent, ectopic, or cystic kidneys)
- identify vesico-ureteric reflux

Patient preparation

- adequate hydration (500 mL of oral fluid 15–30 min before examination) is vital to ensure good diuresis (urine flow of 1–3 mL/min). Avoid study if patient appears clinically dehydrated

Procedure

The patient may be placed supine or erect, reclining against the camera**.** Assess need for catheterization. If not, patient must void before study.

Position patient in either supine or sitting up position. The posture of the patient may have an effect on the renography curve .

A typical adult dose of 50–120 MBq is carefully injected intravenously to avoid local extravasation. An image is taken every 10–20 seconds for up to 40 minutes following administration of radiopharmaceutical.

Analog images are taken every 5 minutes and the hard copy must include several serial analog images as well as the renogram curve. The first 12 and last 12 frames may be summed to exhibit the kidneys more clearly. If the kidney fails to empty by 20 minutes, frusemide may be administered (F+20). Data is collected for 30–45 minutes (or 20 min following diuretic injection). The patient is asked to void at the end of the procedure (minimizes radiation to the bladder as well as allowing assessment of urine production rate). The renogram curve demonstrates change in kidney activity over time.

The radiation activity detected by the gamma camera is first stored as a computer image. Regions of interest (ROI) are mapped out for the kidneys and bladder, in addition to a background region to enable precise measurement of activity count for each time frame. The background region is usually chosen just lateral to the kidneys, but care must be taken to avoid the liver, due to its high tracer uptake.

Additional ROIs (different moieties of a duplex kidney) may also be delineated. The renogram curve can be obtained following subtraction of the background count from the kidney and bladder ROI count and is displayed as a percentage of the injected dose (y-axis) against time (x-axis). The relative function of each kidney is calculated by comparing the percentage dose at 2 and 3 minutes' uptake. Following the procedure, the patient is informed about the possibility of a prolonged diuresis. Frequent voids will help reduce bladder irradiation.

Diuresis

If diuresis renography is indicated, an intravenous bolus of frusemide (dose 1 mg/kg in infants, 0.5 mg/kg in children aged 1–16 years, and 40 mg in adults) is commonly used. Ensure there are no contraindications to diuretic therapy. Frusemide will produce a maximal diuretic response within 5–10 minutes and rationale is to increase the sensitivity of the dynamic renal study by increasing urine flow rates to stress the system, such that minor degrees of obstruction are unmarked. The timing of diuretic administration is a matter of local policy but the various techniques have distinct advantages. The traditional technique (F+20) involves frusemide administration 20 minutes after injection of the radiopharmaceutical. The study must continue for at least 20 minutes following frusemide injection. This enables study of initial unmodified renal handling, followed by the response to increased urine flow rate.

The F-15 technique (frusemide given 15 min before radiopharmaceutical) ensures maximal diuresis at commencement of data acquisition, thereby revealing minor levels of obstruction. Administration of the tracer simultaneously with frusemide (F+0 technique) has been practiced in pediatric units and has the advantage of significantly reducing examination times. The F+0 technique is not recommended in patients with significant renal failure (GFR < 15 mL/min per kidney) and renal units with significant hydronephrosis.

The timing of diuretic does not significantly alter split renal function result, but centers should standardize practice to enable meaningful comparisons (e.g., before and after surgical intervention). The F-15 technique will separate the majority of equivocal curves on F+20 renography in to either unobstructed or obstructed, and therefore is preferred in patients with equivocal results or with gross hydronephrosis.

Factors influencing MAG3 renography

1. Renal function**:** a GFR of <15 mL/min per single kidney will result in urine flow rates of <10 mL/min, with poor subsequent tracer washout. This may result in an “obstructed” (false positive) curve. Frusemide is usually insufficient to increase diuresis significantly and perfusion pressure-flow studies (Whitaker test) ought to be considered. Renal disease affecting the parenchyma (e.g., acute tubular necrosis) may diminish the response to diuretics.

2. Hydration: minor levels of obstruction may be masked in dehydrated individuals. In addition, diuretic administration may be perilous if the patient is already dehydrated. Oral hydration (500 mL of water 30 min before study) will usually suffice although on occasions intravenous fluids may be required.

3. ***Collecting system capacity:*** in the massively dilated system, urine flow may be inadequate to prevent tracer accumulation in the renal pelvis. In such cases, a false-positive “obstructed” curve may be the end result. The F-15 technique will help minimize the effects of a capacious system.

4. ***Collecting system compliance:*** increased diuresis, within a normo-compliant system, should result in distension of the renal pelvis with no signifi cant increase in pressure. However, poor compliance may cause rapid elevations within a non-dilated system, such that any obstruction is overcome and there is reasonable tracer flow distal to the obstruction (false negative). Conversely, a hyper-compliant upper tract will result in renal pelvic tracer accumulation, in spite of the absence of obstruction, resulting in a false-positive curve.

5. ***Bladder effects:*** a full bladder may inhibit drainage from the ureters and cause artifacts. The patient must be asked to void prior to commencement and again before completion of data acquisition. Alternatively, in patients with chronic retention or a neurogenic bladder, catheterization should abolish any effects of a full bladder.

6. *Ureteric dilatation or obstruction*: in cases of gross ureteric dilatation, an ROI drawn around the kidney and renal pelvis may miss the distal obstruction, resulting in a false-negative study. Care must be taken to study the analog images and ROI must include the ureter proximal to the obstruction. Furthermore, multiple simultaneous levels of obstruction will not be apparent by MAG3 renography.

The maximal recommended activity per test is 100 MBq for MAG3 renography, which corresponds to an effective radiation dose of 1 mSv (equivalent to 6 months of background radiation).

Interpretation

Normal renogram curve

The shape of the renogram curve (following subtraction of background activity) is dependent on—

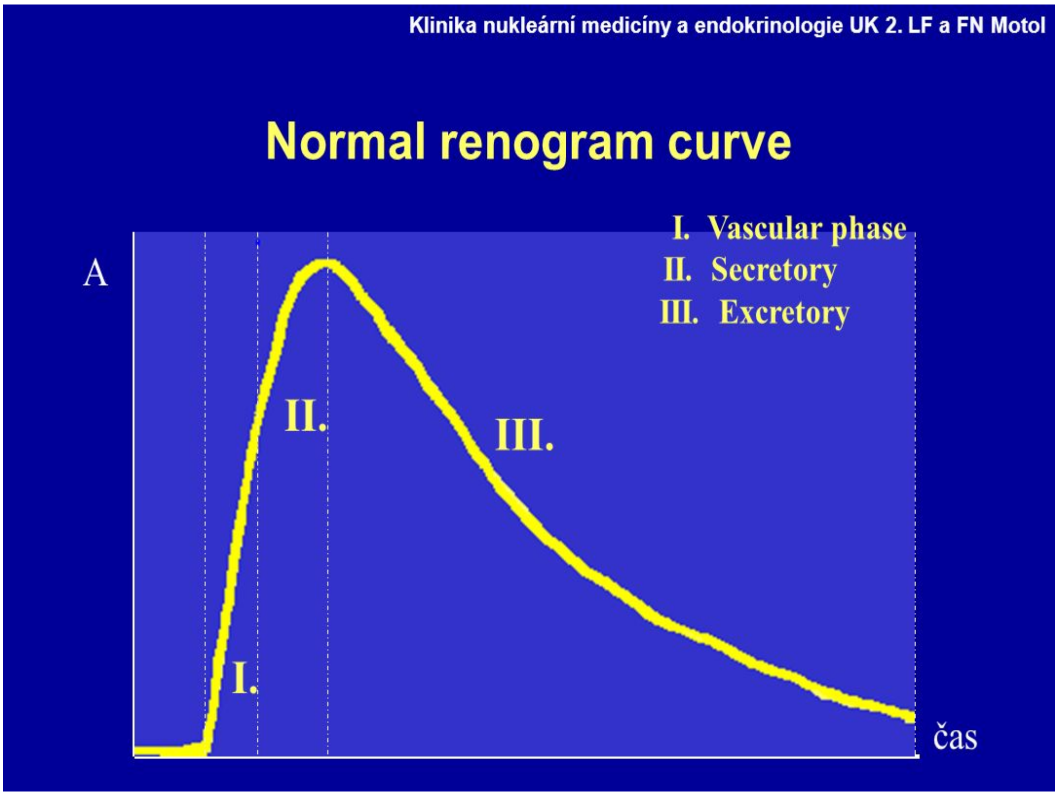
1. MAG3 uptake from blood into kidney
2. MAG3 elimination from kidney into bladder

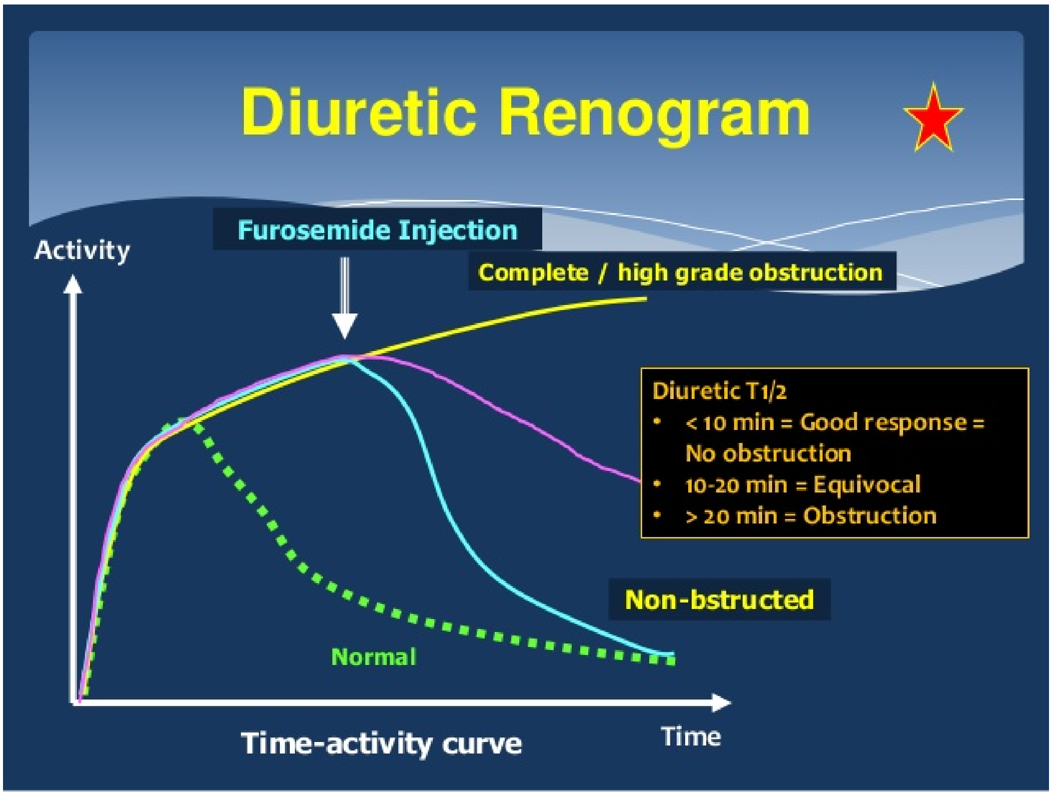
Classically, the normal MAG3 renogram curve has **three phases:**

• ***The first phase***: steep upward rise following intravenous contrast injection; this is indicative of the speed of tracer injection and its delivery to the kidneys (i.e., renal vascular supply).

• *The second phase:* a more gradual slope which represents renal handling of MAG3 (renal uptake by tubular secretion and glomerular filtration) and peaks between 2 and 5 minutes. Time taken for the curve to peak following tracer injection is referred to as Tmax. This may be delayed in patients with renovascular insufficiency, renal failure, and obstruction

• *The third phase:* commences after the peak. Associated with the emergence of tracer in the bladder. Represents elimination (but also delivery) of tracer from the kidney. After 3 minutes both elimination and uptake are in competition, but the former subsequently dominates. It is this elimination curve that is dependent on the upper tract urodynamics. The elimination curve may have a smooth or stepwise (variant of normal) pattern and when normal, excludes the presence of obstruction. A delayed upward deflection may indicate intermittent obstruction or vesico - ureteric reflux.





Split renal function

This is expressed as the ratio of the area under the renogram curves of the two kidneys obtained during the period 40 seconds to 2 minutes 40 seconds after tracer injection. The shortest transit time for filtrate in the Bowman's capsule to the renal pelvis is 2.5 minutes, and therefore it can be safely assumed that the MAG3 will not be found in the collecting system within 2.5 minutes of injection. The initial 40 seconds are excluded to prevent artifact errors. The relative function in a pair of normally working kidneys may vary between 40% and 60%. Similarly, relative functions in different moieties of a duplex kidney can also be calculated.

Scarring

Since 80% of MAG3 is metabolized by tubular secretion, the analog images can be analyzed for the presence of parenchymal scarring. Although DMSA renography remains the gold standard for the investigation of scarring, MAG3 studies show good correlation between the two techniques.

Renogram curve patterns

When interpreting MAG3 renography, five distinct patterns (based on the F+20 technique) are recognized. It is important not merely to assess the shape of the curve, but also to examine the sequential analog images to determine the level of obstruction, as the calyces, pelvis, and ureter may all be easily visible

Type I—normal response

This is characterized by a rapid uptake curve leading up to a peak within 2–5 minutes, followed by gradual (but sometimes stepwise) elimination of tracer. Administration of furosemide results in no appreciable difference in speed of elimination. A normal curve virtually excludes obstruction, although it may be argued that increasing urine flow rate (i.e., using the F-15 technique) may expose lesser degrees of impedance.

Type II—obstructive response (high-pressure system)

In the absence of any other factors affecting drainage (e.g., dehydration, renal impairment, etc.), an obstructive pattern is denoted by a rising curve. In addition, the lack of an exponential tracer elimination curve is also suggestive of a degree of obstruction. Typically, there is little or no response to frusemide. On the analog images, the affected kidney will often display good parenchymal uptake and accumulation of tracer above the level of obstruction (e.g., in the renal pelvis in patients with UPJO). The diagnosis of obstruction cannot be satisfactorily made (even in the presence of a rising curve) if the affected kidney has a GFR of <15 mL/min, since the rate of urine production may be in sufficient to produce tracer washout (usually 1–3 mL/min urine production is required).

Type IIIa—dilated but not obstructed (low pressure/hypotonic system)

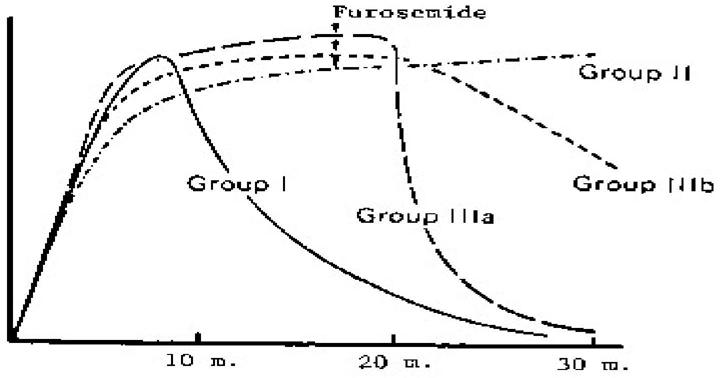
There is an initial accumulation of tracer in the kidney, resulting in a rising curve similar to an obstructive response, but there is prompt elimination following furosemide injection. The analog images usually demonstrate tracer accrual in a dilated system secondary to stasis rather than obstruction. The increased urine flow produced by the diuretic is adequate to effect free drainage.

Type IIIb—equivocal response

Following an initial “obstructed” rising curve, a furosemide injection produces a somewhat languid response. The curve demonstrates some tendency to washout, albeit incompletely. Examination of the analog images may help clarify whether this represents partial obstruction or inadequate tracer elimination (e.g., due to a dilated renal pelvis). In this situation, an F-15 study will help categorize the majority of equivocal curves into either obstructed or non-obstructed.

Type IV—delayed compensation (Homsy’s sign)

Described by Yves Homsy in 1988, the characteristic shape is a “double peak” response to diuretic. This pattern is seen in patients with subclinical intermittent obstruction. A repeat F-15 diuresis renography will often reveal an obstructed pattern. The first “peak” is due to an initial rising curve, which then exhibits a good response to furosemide. However, as the diuretic effect increases, the threshold is reached and tracer accumulation causes the curve to either flatten or rise.



Modifications of the MAG3 renography

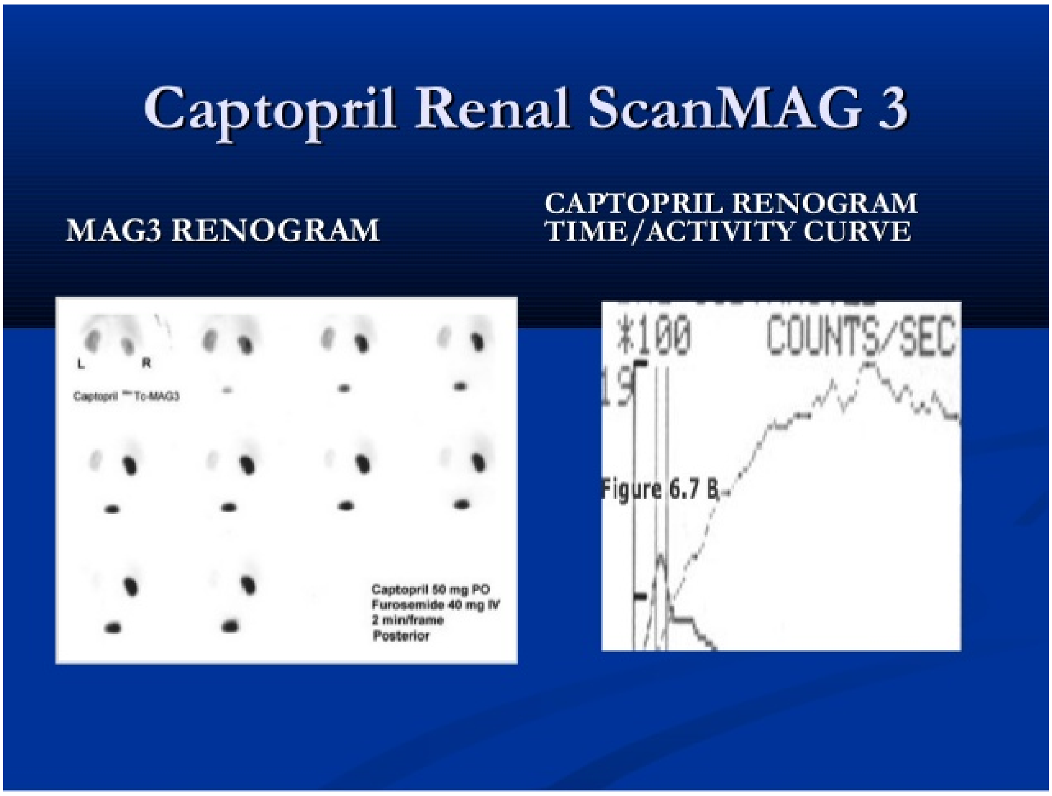
Deconvolution analysis

This is a mathematical manipulation of the renogram to produce a theoretical curve that would be derived if the tracer had been injected in the renal artery (rather than a peripheral vein). This allows calculation of a range of transit times through the renal tubules, including mean parenchymal transit time as well as whole kidney transit time. Transit times are increased in obstruction and renal failure. Attention to technical detail is paramount, and as yet deconvolution techniques have not gained widespread acceptance.

Captopril-enhanced renography

This modification is indicated for the investigation of renal artery stenosis. Patients should be instructed to stop any angiotensin converting enzyme (ACE) inhibitor or diuretics for at least 3 days prior to examination. Ensure patient is well hydrated. A baseline study is performed first. Following this, a further study is repeated (on the same day or consecutive days) with 25 mg of Captopril (ACE inhibitor) given orally 1 hour before tracer injection. Renin converts angiotensinogen to angiotensin I, which in turn is converted (by an ACE) into angiotensin II. Angiotensin II effects efferent arteriole vasoconstriction and thereby maintains GFR.

Patients with renovascular (e.g., renal artery) stenosis have higher levels of angiotensin II. The captopril-enhanced renogram therefore will display reduced function (reduced gradient in the uptake part of the curve) and delayed transit, with a delay in Tmax (time taken for renogram curve to peak) (see fi g 4.2). The overall sensitivity of this technique is 80–90% for the detection of renovascular hypertension, and patients with positive results can often be successfully treated.



Advantages of MAG3 renography

• provides sensitive indices of tubular function and urinary excretion

• virtually no contraindications

• non-nephrotoxic

• no significant risk of allergic reactions

• serial examinations possible (often required)

• side effects are rare (unless frusemide or captopril is used)

Disadvantages

• exposes patient to radiation

• length of study (can take up to 1 hour)

• prone to artifact errors (e.g., due to renal impairment, posture, bladder effect, etc.)

• limited anatomical information

• equivocal results require a repeat procedure (usually F-15 study)

• inaccurate outlining of ROIs can affect curve dynamics

11.2 DMSA renography

• 99mTc-DMSA ***(dimercaptosuccinic acid)*** has a high affinity for the renal cortex

• 99mTc-DMSA is the preferred radiopharmaceutical for static parenchymal imaging

Provides the most accurate assessment of relative renal function compared to other tracers.

Following tracer injection, 99mTc-DMSA is mostly plasma protein bound, and therefore clearance by GFR is minimal. In the kidney, the cells of the proximal convoluted tubules (and the distal tubules to a lesser extent) extract the 99mTc-DMSA by tubular secretion allowing slow concentration of radioactivity in the renal cortex. After 3 hours, about 50% of the injected tracer is concentrated in the kidneys, remaining there for up to 24 hours. The majority of the other 50% is excreted unchanged in urine. Increased hepatic accumulation, and subsequent biliary excretion is noted in patients in renal failure. Owing to the slow renal extraction of 99mTc-DMSA, the optimal time for imaging is between 2 and 4 hours after tracer injection. 99mTc-DMSA scanning represents functioning tubular mass, yields excellent cortical images, and is an invaluable tool in the assessment of both adults and children.

Indications

• assessment of relative renal function

• detection of renal scarring with a sensitivity of 96% and specificity of 98% (due to urinary tract infections or reflux nephropathy in children)

• investigation of renal anomalies (e.g., horseshoe, solitary, or ectopic kidneys)

• examination of space occupying renal lesions

Procedure

The optimal time for DMSA scanning remains an unresolved issue. Many units perform the study in the acute phase (i.e., during or soon after a UTI) in order to determine the extent of parenchymal involvement. Critics of such practice point out that an acute abnormality does not necessarily represent a permanent scar and a repeat scan is often required after 3–6 months to determine longstanding injury. Deferring the DMSA scan for such a period of time may avoid the initial examination.

99mTc-DMSA has no specific contraindication and no specific patient preparation is required, since uptake is independent of the hydration state

• A typical adult dose of 80–100 MBq (1 MBq/kg body weight) is injected into a peripheral vein.

• Images are acquired after 2–6 hours (usually after 3 h). Imaging must be avoided within the first hour due to the presence of free 99mTc in urine.

• Regions of interest are created around both kidneys as well as a background area between the kidneys. Subtraction of the background area count from the overall kidney count will result in the correct kidney count.

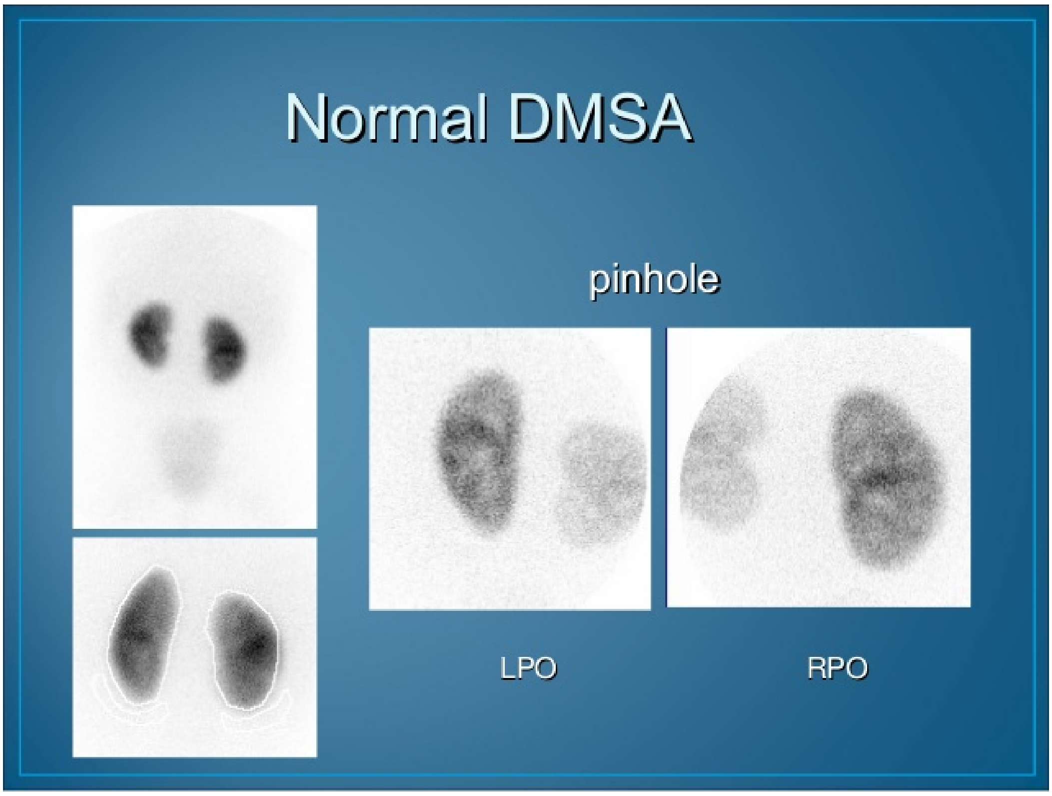
To maximize the detection of scarring, various projections should be utilized to image the kidney. Posterior, right, and left posterior views are standard, but anterior views must be included if a pelvic or horseshoe kidney is suspected. Furthermore, in asymmetric kidneys (e.g., ectopic kidneys, scoliosis), anterior views must be obtained and split function expressed as a geometric mean of radioactivity in both posterior and anterior images.

A typical dose of 80 MBq for DMSA renography corresponds to an effective radiation dose of 1 mSv (equivalent to 6 months of background radiation).

Interpretation

Normal kidneys should have a homogenous parenchymal distribution with visible demarcation between the cortex and medulla. Preservation of cortical thickness is indicative of acute changes, while cortical thinning is in keeping with chronic damage. The size, shape, and location (normal or ectopic) of the kidneys is readily demonstrated. Scars or other deformities are seen as areas of decreased or absent activity within the parenchyma.

Artifacts may arise in kidneys with congenital fetal lobulations or due to splenic overlapping of the left kidney.



Advantages

• provides excellent cortical images

• accurate split renal function estimation

• non-nephrotoxic

• no signifi cant complications

• allergic reactions are exceptionally rare

Disadvantages

• involves radiation

• does not allow dynamic assessment of renal excretion

11.3 Obtaining glomerular filtration rate (GFR)

Indications

General indications for GFR estimation include—

• any clinical situation requiring an accurate measurement of absolute renal function

• follow-up in patients with chronic renal disease

• prior to administration of nephrotoxic therapy (e.g., chemotherapy)

• GFR estimation is invaluable in the management of patients with or at risk of renal impairment

• GFR is defined as the volume of blood from which a solute is cleared by glomerular filtration through the Bowman's capsule per unit time (mL/min)

• GFR is regarded as a measure of global function

The ideal radioactive tracer for this purpose would have the following properties:

• be cleared solely, completely, and unmodified by glomerular filtration

• should not undergo tubular secretion or resorption (any tubular secretion will increase the resultant GFR value)

• be non-toxic, stable, and not bound to serum proteins

• be readily measured in blood or urine

• should have a constant clearance irrespective of plasma concentration

Patient preparation

No specific patient preparation is required, but ensure that the patient is well hydrated and empties the bladder prior to injection.

Procedure

• Doses used are 10 MBq for 99mTc DTPA and 3 MBq for 51Cr
EDTA

• A pre-tracer injection venous blood sample is taken for background
activity

• The tracer is injected and the exact time noted

• A heparinized blood sample is taken at 90, 150, 210, 270 minutes following injection and corrected (minus background activity) plasma tracer concentration can be plotted against time. Studies have shown that a minimum of four blood samples are required for accurate results

• Plotting the log of tracer concentration will result in a linear curve. Extrapolation of this line back to time zero will indicate the effective volume of distribution. The GFR is then calculated as the product of the distribution volume and the slope of the linear log curve, using the formula

GFR = V λ

where λ is the slope and V is injected tracer dose/distribution dose

The *Gates* technique for GFR estimation, though not in common use, involves analysis of tracer activity in the kidneys between the 2- and 3-minute intervals following tracer injection. While the obvious advantage of this technique is the speed of the test and the absence of blood tests, its accuracy has been doubted. This technique has therefore fallen out of favor and most centers use a serial venous sampling method.

An alternative to blood sampling is using three urine samples over 3 hours to measure urinary tracer concentration, but difficulties and inaccuracies in specimen collection make this method unattractive.

A typical dose of 10 MBq for 99mTc DTPA and 3 MBq for 51Cr for EDTA for GFR studies corresponds to reasonably small effective radiation doses of 0.1 mSv and 0.007 mSv, respectively. It is therefore feasible to perform serial studies safely if clinically indicated.

Interpretation

Although cumbersome, these single injection filtration markers techniques provide a more accurate GFR reading than that obtained with traditional creatinine based methods. The GFR value obtained may be used uncorrected to evaluate changes in renal function for an individual patient. However, since GFR varies with age, gender, and body mass, it is recommended that a normalized GFR based on the standard body surface area of 1.73 m2 be used for comparisons.

• Normal values are 130 mL/min/1.73 m2 (men) and 120 mL/min/ 1.73 m2 (women) with a variation coefficient of 14–18%

• Normalized GFR for the newborn is almost half that of the adult, with a gradual increase to adult values by the age 2

• GFR declines by roughly 1% per year after age 40

• Other factors affecting the GFR are time of day (10% higher in the afternoon than at midnight); pregnancy (up to 50% higher in the first trimester); high protein meal (gradual rise in GFR within an hour), and exercise (a transient reduction occurs)

Advantages

• accurate

• no need for 24-hour urine collections

• mandatory in clinical trials investigating progressive renal failure

Disadvantages

• invasive repeated blood samples

• involves a small amount of radiation

• lengthy procedure

• artifacts can be caused by inaccurate recording of times, tracer extravasation at injection site, signifi cant edema, or as cites (due to altered body compartment distribution)

11.4 Radionuclide cystography

This is the radionuclide analogue of X-ray micturating cystography with iodinated contrast media. In outline, the bladder is filled with fluid containing a non-absorbable radiotracer, and dynamic imaging of the urinary tract is carried out during micturition in order to detect vesicoureteric reflux. This may be achieved with direct instillation of the tracer into the bladder, but this approach does not capitalize on the major advantage of the radionuclide technique, which is the possibility of avoiding bladder catheterization. Much more clinically useful is the technique of indirect cystography, which is basically similar but which uses as a starting point the full bladder at the end of a conventional dynamic renal study. Using 99mTc-MAG3, renal activity normally falls off to a considerable extent by the time the bladder is full, so the presence of baseline counts in the background and in the kidneys at the start of micturition is not a significant disadvantage.

Types

Direct radionuclide cystography (DRC) requires catheterization of the bladder and instillation of radionuclide and fluid for maximum distension of the bladder, allowing imaging during filling, voiding and after voiding.

Indirect radionuclide cystography (IRC) does not require bladder catheterization but does require the intravenous injection of the radiopharmaceutical for evaluation of renal function, urine drainage, as well as detection of vesicoureteral reflux.

Indications

* detection vesicoureteric reflux
* initial evaluation of females with urinary tract infection for reflux
* diagnosis of familial reflux
* follow-up of vesicoureteral reflux following a course of antibiotic therapy
* assessment of the results of anti-reflux surgery
* serial evaluation of bladder dysfunction (e.g., neurogenic bladder) for reflux

Patient Preparation

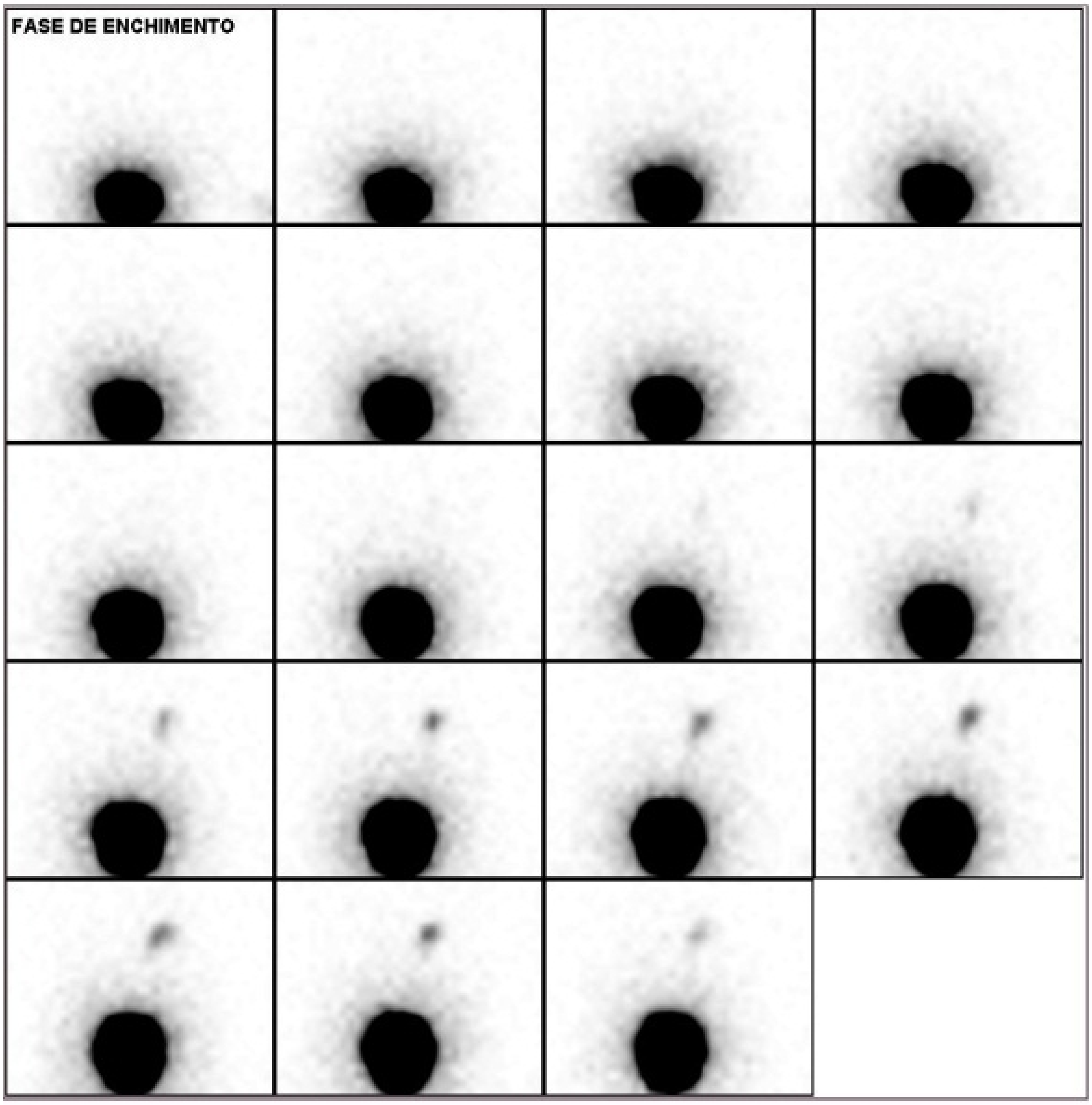
There is usually no preparation necessary

Procedure

This is basically as for diuretic renography, described earlier. After completing the initial part of the study, including the response to diuresis, the patient is placed in a sitting or standing position and the camera repositioned to include both kidneys and the bladder within the field of view. Image frames of 5-10 s duration are collected during micturition. Time-activity curves are derived from the region of the bladder, each kidney individually, and also from regions along the line of each ureter.

Interpretation

Vesicoureteric reflux is confirmed if there is an increase in kidney counts during micturition. Lesser degrees of reflux may appear as increased counts in the ureters, which may be transitory.



radionuclide cystography: right vesicoureteral reflux.

Advantages

- direct radionuclide cystography, using short half-life radiopharmaceuticals, is considered to be more reliable for detecting vesicoureteral reflux than conventional roentgenographic techniques
- the theoretical advantages of indirect radionuclide cystography are that unpleasant catheterization is avoided, voiding may be more normal because the urethra is not irritated, the study is performed without overdistending the bladder, and renal function and morphology, as well as reflux, may be evaluated simultaneously

- the major advantage of nuclear cystography is the small radiation dose delivered with its use

Disadvantages

- a major disadvantage of direct radionuclide cystography is poor resolution, prohibiting analysis of small bladder defects and urethral abnormalities
- the disadvantages of the indirect cystography include its dependence on renal function and drainage, as well as on cooperation by the patient who mast be able to void on request
- the study is not practical in children who have a neuropathic bladder and in those who are not toilet trained
- the radiation dose is higher than that of the direct cystogram and may become considerable if the child withholds urine for a protracted period.

12. Positron emission tomography (PET) scan

PET is a nuclear medicine functional imaging technique that is used to observe metabolic processes in the body. The system detects pairs of gamma rays emitted indirectly by a positron-emitting radionuclide (tracer), which is introduced into the body on a biologically active molecule. Three-dimensional images of tracer concentration within the body are then constructed by computer analysis. In modern PET-CT scanners, three-dimensional imaging is often accomplished with the aid of a CT X-ray scan performed on the patient during the same session, in the same machine.

Indications

PET may contribute in the following pathological processes:

- Testicular tumors
  - primary tumor staging
  - early detection of recurrent disease
  - assessment of residual tumor burden after therapy
- Renal cell cancer
  - initial staging of local and distant disease
  - detection of recurrence

- bladder cancer
- detection of recurrent disease (if other imaging ambivalent)
- Detection of bony metastases (if bone scan equivocal)

The are no specific contraindications to PET scanning except for women who are pregnant and breastfeeding.

Patient preparation

• patients advised to avoid food for 4–6 hours and oral intake restricted to non-sugary clear fluid

• blood glucose estimation is performed just prior to the examination to ensure low glucose levels (high levels inhibit FDG uptake by cells)

• in addition, buscopan (20 mg) and/or diazepam may be administered to reduce FDG uptake by the intestines and muscles, respectively

• a preliminary background scan is performed before up to 400 MBq of FDG is injected intravenously

• imaging is performed between 45 and 90 minutes after tracer injection

• a whole body scan can be performed or imaging restricted to the area of interest, with or without simultaneous CT scanning

A maximal injected dose of 400 MBq corresponds to an effective radiation dose of 10 mSv (equivalent to up to 6 years of background radiation).

Procedure

In nuclear medicine studies, the planar imaging commonly utilized provides a tracer distribution image in two dimensions. The basic aim of PET scanning is to create an image representing three-dimensional (3D) distribution of tracer, by combining the use of positron-emitting radionuclides and emission CT. Initially, a research tool for a number of years, PET scanning is now emerging as a useful clinical tool in the management of patients with a variety of pathological conditions, although its efficacy for the urological patient is still undetermined.

Certain radioisotopes decay by releasing positrons, which are positively charged electrons. These positrons travel short distances (less than 2.5 mm) and collide with other electrons, which results in the release of two high-energy (511 keV) photons emitted at 180° to each other. The PET scanner comprises several rings of multiple crystal detectors which detect the emitted photon, thereby reconstructing a 3D image of tracer distribution within the body.

One of the advantages of PET scanning is that it utilizes isotopes of elements ubiquitous in the human body and therefore is able to image physiologically important chemicals throughout the body, providing useful functional and metabolic information.

The mainstay of clinical PET scanning is 18fluorine (half-life 2 h) which is used to produce 18fl uorine-2-D-deoxyglucose (18FDG), an analog of glucose. FDG, like glucose, is preferentially transported in tumor cells via specific glucose transporters, due to their inherently increased rate of metabolism and glycolysis. Once within the cell, FDG undergoes phosphorylation by hexokinase to form FDG-6-phosphate, following which it becomes inert and takes no further part in glycolytic pathway. It remains trapped in the tumor cell, and subsequent accumulation will eventually increase tracer activity to levels detectable by the PET scanner. The tracer is excreted through the kidneys. Because small amounts of tracer can be visualized, early tumor detection is possible even before other cross-sectional imaging (like CT or MRI) can detect structural changes. Other tracers, apart from FDG, continue to be developed and tested but remain some way off from entering the clinical setting.

A dedicated full ring PET scanner is the gold standard, but it is expensive. An acceptable alternative is to use a modified multihead gamma camera. This has the advantage in that it is cheaper and can be used for SPECT imaging. Though costly, a dedicated PET scanner is quicker, more sensitive, has superior resolution compared to the gamma camera, and does not require a collimator. Combining a CT scanner and PET scanner within a single imaging scaffold will provide excellent anatomical as well as functional information and is likely to become the PET imaging technique of the future.

Interpretation

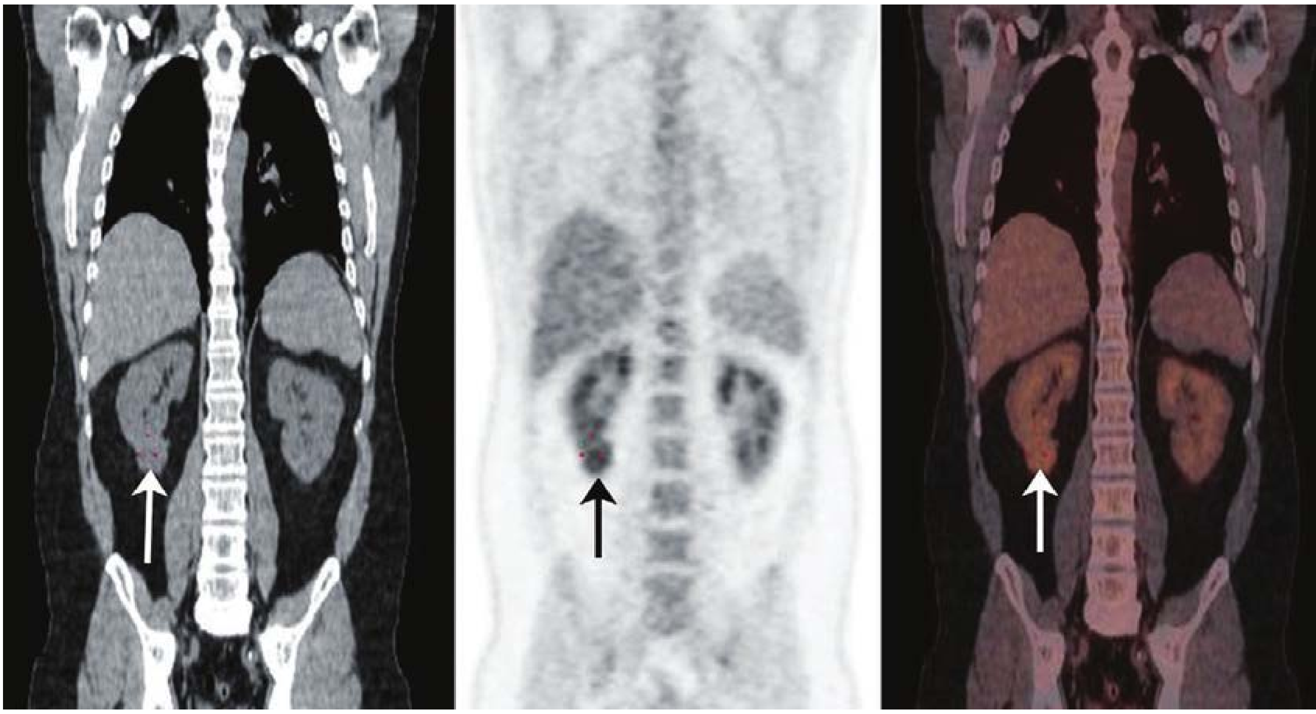
Since FDG-PET is a function of glucose metabolism, any organ with a higher metabolic rate will demonstrate greater tracer activity under normal circumstances (e.g., brain, intestines, liver, heart, etc.). Tracer uptake by malignant lesions will also depend on the rate of glycolysis. Although most tumors will demonstrate an inherently higher metabolic rate, some tumors (e.g., prostatic cancers) may have decreased proliferative activity and therefore not be apparent on PET images. The lower limit of the size of lesion detectable by PET scanning is 5 mm in diameter but is likely to improve in the future with improved resolution scanners PET is inferior to conventional bone scintigraphy in the detection of skeletal metastases but can be used to provide additional information if the latter is equivocal.

Advantages

- uses biologically important radionuclides to provide pertinent functional and metabolic information
- proven efficacy in other non-urological cancers
- generally high specificity for malignant disease
- whole body can be imaged at once
- spatial resolution of 5 mm
- can be combined with simultaneous CT to improve image resolution

Disadvantages

- involves radiation
- length of procedure
- expensive (cost of collimator, scanner, and radiochemistry facility is high)
- radionuclides with a short half-life may need to be produced on site
- lack of anatomical landmarks (especially in the thorax and abdomen)
- urinary excretion limits detection of bladder and prostate malignancies



Fluorine-18 fluoro-2-deoxy-D-glucose (FDG) positron emission tomography (PET)/CT appearances of a renal cell carcinoma (RCC) with intermediate grade uptake. Unenhanced CT image (left) demonstrates an exophytic lesion seen in the lower pole of the right kidney (arrow). PET image (centre) and fused PET/CT image (right) demonstrate low grade uptake in the lesion (arrows) similar to background renal uptake. This was a histologically confirmed RCC showing only low to intermediate grade FDG uptake.

13. Renal angiography

Angiography, the study of the vascular system, is performed by injection of water-soluble contrast media intra-arterially (or intravenously, for venous studies) through a percutaneously placed catheter under fluoroscopic guidance. Pathologic processes involving both the vasculature and parenchyma can be characterized by fluoroscopic monitoring using either digital or conventional image recording.

Indications

• ***assessment*** of vascular disease (atherosclerosis, aneurysm, vaculities)

• determination of vascular injury

• vascular mapping for preoperative purposes (organ transplantation) or prior to therapeutic interventions (stent placement)

• detection arteriovenous malformations and fistulas

- characterization of tumor vascularity prior to endovascular procedures (embolization)
- assessment of renal masses
- differentiation renal cysts from tumors
- evaluation hypertension
- angiography of the bladder and prostate is also largely performed as a prelude to intervention for troublesome or life-threatening hematuria, either due to inoperable tumor or postsurgical (usually transurethral prostatectomy) bleeding

Patient preparation

Before the procedure, a laxative may be prescribed to evacuate the colon so that unobstructed x-rays can be obtained.

Procedure

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.

inferior vena caval filter

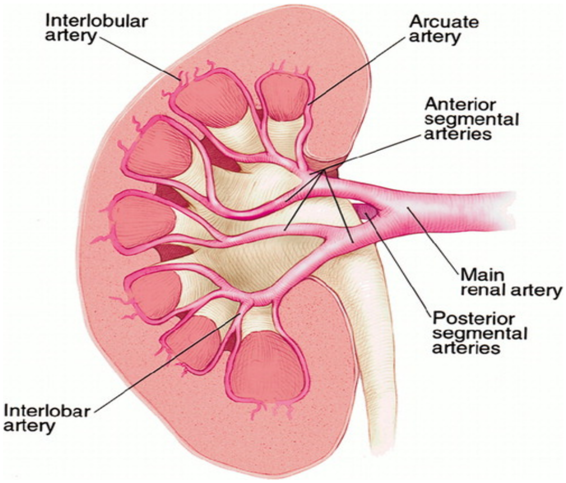
An expandable wire mesh basket (arrows) has been placed in the inferior vena cava. This can be done by pushing the device out of a catheter and allowing it to expand in place. This will keep the large clots from traveling from the lower extremities and pelvis up the inferior vena cava and into the lung.

Normal renal vascular anatomy

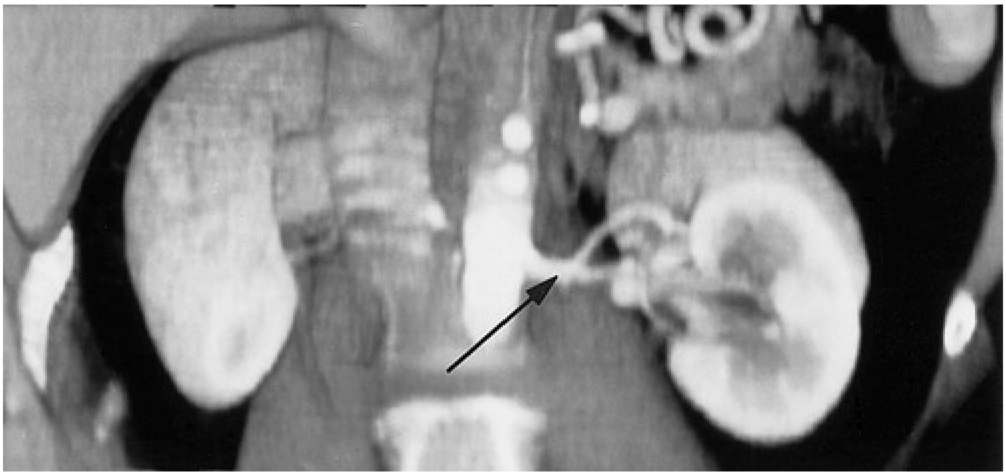
Renal Arteries

In most individuals, each kidney is supplied by a single renal artery that originates from the abdominal aorta. The renal arteries typically arise from the aorta at the level of L2 below the origin of the superior mesenteric artery, with the renal vein being anterior to the renal artery. The renal arteries course anterior to the renal pelvis before they enter the medial aspect of the renal hilum. The right renal artery typically demonstrates a long downward course to the relatively inferior right kidney, traversing behind the inferior vena cava. Conversely, the left renal artery, which arises below the right renal artery and has a more horizontal orientation, has a rather direct upward course to the superiorly positioned left kidney. Both renal arteries usually course in a slightly posterior direction because of the position of the kidneys.

The main renal artery divides into segmental arteries near the renal hilum. The first division is typically the posterior branch, which arises just before the renal hilum and passes posterior to the renal pelvis to supply a large portion of the blood flow to the posterior portion of the kidney. The main renal artery then continues before dividing into four anterior branches at the renal hilum: the apical, upper, middle, and lower anterior segmental arteries. The apical and lower anterior segmental arteries supply the anterior and posterior surfaces of the upper and lower renal poles, respectively; the upper and middle segmental arteries supply the remainder of the anterior surface. The segmental arteries then course through the renal sinus and branch into the lobar arteries. Further divisions include the interlobar, arcuate, and interlobular arteries. Depiction of the relatively avascular plane between the anterior and posterior arterial divisions of the kidney is important to the surgeon, because the site can be used for a clean incision toward the renal pelvis at the time of surgery. The site is usually located posteriorly, one-third of the distance between the posterior and anterior kidney surfaces. A similar avascular plane exists between the posterior renal segment and the polar renal segments.



normal anatomy of the renal arteries

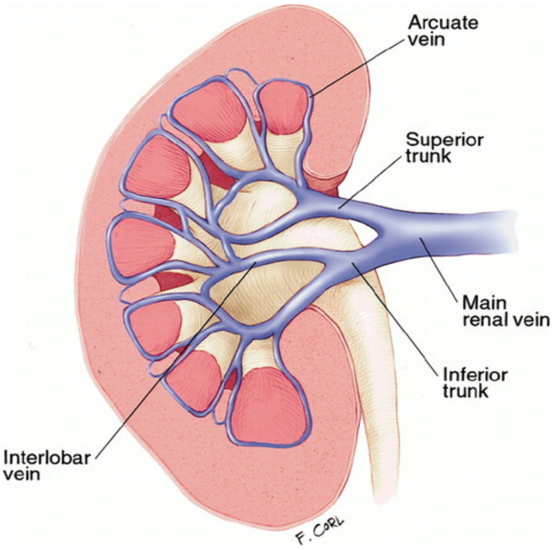


normal renal arteries

Anterior volume-rendered image from CT data shows prepolar branching of the left renal artery (arrow).

Renal Veins

The renal cortex is drained sequentially by the arcuate veins and interlobar veins. The lobar veins join to form the main renal vein. The renal vein usually lies anterior to the renal artery at the renal hilum. The left renal vein is almost three times longer than the right renal vein. The left renal vein averages 6–10 cm in length and normally courses anteriorly between the superior mesenteric artery and the aorta before emptying into the medial aspect of the inferior vena cava. The right renal vein averages 2–4 cm in length and joins the lateral aspect of the inferior vena cava. Unlike the right renal vein, the left renal vein receives several tributaries before joining the inferior vena cava. It receives the left adrenal vein superiorly, the left gonadal vein inferiorly, and a lumbar vein posteriorly.



normal anatomy of the renal veins

Advantages

- arteriograms give the best pictures of the arteries
- arteriograms are used to make specific diagnoses and to help determine what is the best treatment in a particular case
- often, the treatment itself can be performed using the same type of catheters used in the arteriogram.

Disadvantages

- the angiogram plays little role in diagnostic evaluation of the renal parenchyma, having been supplanted by cross-sectional imaging techniques
- invasive procedure
- bleeding and injury to the artery
- contrast complications
- risk of complications is higher in the elderly, although it is still low

- the radiation dose used in angiography can vary and be significant (e.g., coronary angiography is associated with an effective radiation dose of 4.6 to 15.8 mSv)

14. CT angiography

CT angiography is an extremely useful investigation but exposes the patient to a considerable amount of radiation and should not therefore be used as a first-line investigation.

Indications

- renal artery stenosis
- renal artery aneurysm, dissection or thrombosis
- arteriovenous malformation
- delineation of vascular anatomy prior to laparoscopic surgery
- renal vein thrombosis
- tumor

Patient preparation

The same preparation as for CT.

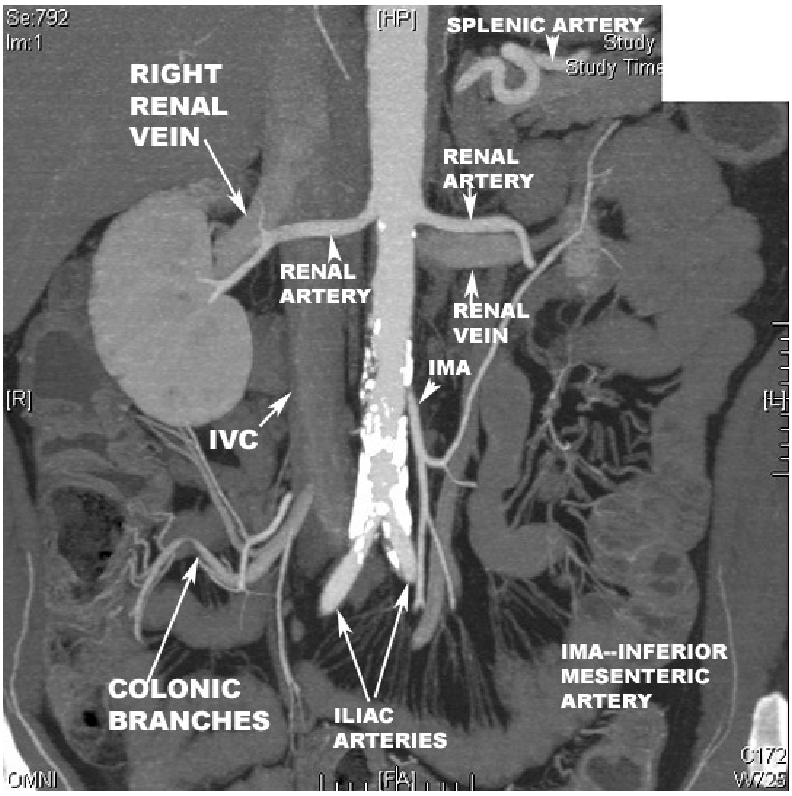
Procedure

recommended protocol for CT angiography of the renal vasculature

1. A large-bore (18-gauge) intravenous line is placed in the antecubital fossa.
2. The patient is given water orally. Water is used as a negative contrast agent because a positive orally administered contrast agent would interfere with the 3D rendering to follow.
3. The patient is instructed in breath-hold technique. Most CT scanners require a 30- to 40-second breath hold for obtaining optimal images of the renal hilum. Newer multidetector helical CT scanners are much faster, and a breath hold of only 10–20 seconds is needed.
4. In select cases, the renal hilum is localized accurately by obtaining a few nonenhanced images. The appropriate table position is calculated for

evaluation of the renal hilum. The region of interest for scanning extends from the suprarenal abdominal aorta to the iliac artery bifurcation.

5. Helical CT scanning parameters are entered. Use of narrow collimation (1–3 mm) is crucial. A pitch up to 2 is used to ensure adequate coverage and will not substantially decrease image quality. Newer multidetector scanners allow an even greater pitch (up to 8) to be used without incurring image degradation.
6. Contrast material is injected at 3–4 mL/sec for a volume of 120–150 mL
7. The helical acquisition of image data is initiated after a preset empiric delay of 20–25 seconds after the start of the contrast material injection. Use of bolus triggering devices should be considered to ensure appropriate timing, especially in examinations of older patients with decreased cardiac output.
8. Images are reconstructed equally throughout the data set. For evaluation of the renal hilum, use of 1-mm interscan spacing is ideal (especially for assessing renal artery stenosis). For routine anatomic evaluation, 3-mm interscan spacing is suitable.
9. Data are transferred over the network to an imaging workstation.



normal renal CT angiography

Advantages

- CT angiography is a powerful and cost effective tool for vascular imaging suited for critically ill patients
- CT angiography provides excellent spatial resolution in all directions
- images can be reconstructed in multiple planes and maximum intensity projection performed for a 3D display

Disadvantages

- in comparison with MRI angiography, CT angiography needs an iodinate contrast medium; this is an imperative drawback of CT angiography and may be unacceptable in those patients with severe renal dysfunction
- CT angiography is somewhat low resolution examination in comparison with catheter angiography
- CT does not allow for functional measurements such as flow direction or flow rates

- in patients with larger body habitus, CT angiography performed with narrow collimation can have an unacceptably low signal - to - noise ratio.

15. MR angiography

Magnetic Resonance Angiography involves the use of magnetic resonance imaging to examine blood vessels in key areas of the body.

Indications

- renal vascular malformation
- for the evaluation of renal artery stenosis
- hypertensive chronic kidney disease
- atherosclerotic renal artery stenosis
- fibro muscular dysplasia
- renal artery aneurism
- renal artery dissection
- renal donors

Patient preparation

It is important to first evaluate the patient's ability to hold his or her breath. The patient's breath-hold capacity dictates MRA scan duration, which should be prescribed to be short enough to enable patient compliance and successful breath-holding. Scan parameters should then be adjusted for the highest possible spatial resolution for sufficient anatomic coverage of the aorta, iliac and renal arteries back to at least mid-kidney. Patients who have a respiratory rate of less than 20 breaths per minute (bpm) can easily suspend breathing for 30-40 seconds which makes high resolution renal MRA easy. But in patients who can only hold their breath for 15 or 20 seconds, it may become necessary to compromise on the desired spatial resolution and coverage. Oxygen may help patients who are dyspneic to double their breath-holding capacity. Even when patients are holding their breath there may still be motion of the kidneys. Thus, it is important to ensure that patients hold their abdomen still in addition to holding their breath.

It is better to start the intravenous line (IV) in the right arm because this provides a more direct path to the central circulation when compared to the left arm. In older patients, the left brachiocephalic vein may get pinched in between the sternum and an ectatic and tortuous aorta thereby interfering with the bolus injection of contrast.

Procedure

• Sagittal black blood sequence (~ 4 minutes) or a 3-plane gradient echo localizer (30 seconds).

• Axial and coronal T2-weighted single shot fast spin echo (1 minute).

• Coronal 3D dynamic Gd-enhanced acquisitions (20 to 30 seconds per phase) repeated during arterial and venous phases with 2 separate breath-holdings. State of-the-art is a matrix of 512 x 192, ~30° flip angle (60-75° when there is a non-magnetic stent) with 2-3 mm thick slices zero-filled down to 1-1.5 mm

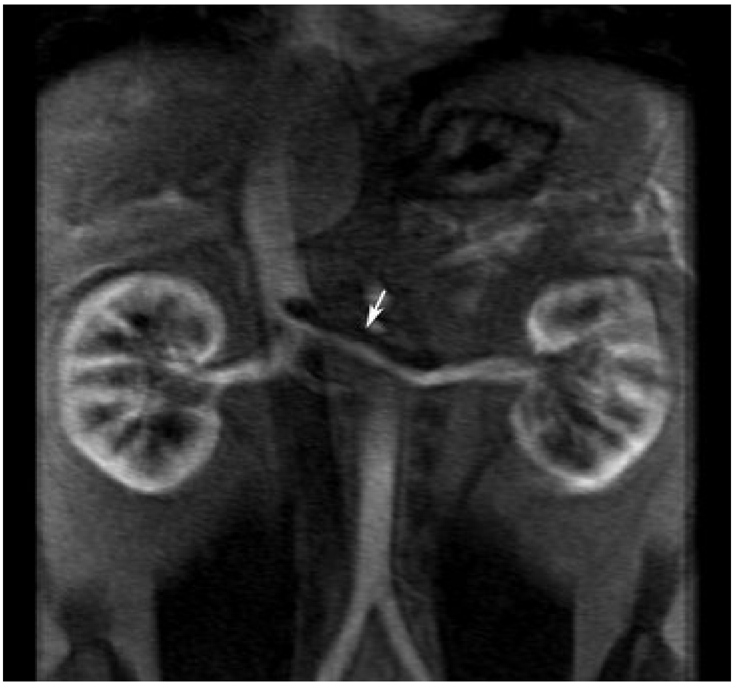
• Axial 3D phase contrast (~7 minutes with velocity encoding @ 30-50 cm/second).

• Post Gd coronal 3D of the renal collecting system (~30 seconds).

The total imaging time is about 15 minutes, giving a total examination time of about 30 minutes with patient set up, breath-holding instruction, etc.

An optional sequence for measuring blood flow in the renal artery is 2D cine phase contrast MRA. The temporal and spatial resolution must be adapted to make the scan short enough to acquire in two breath-holds: one breath hold for each renal artery. For measurement of renal blood flow, it is better to sacrifice spatial resolution in order to preserve temporal resolution.

The standard dose of gadolinium contrast agent for renal MRA is 0.2 mmol/kg (~30 mL) with 40 mL saline flush both injected at a rate of 2 mL/second. Favorable results with 0.1 mmol/kg have been reported with Gd-BOPTA , which has a two-fold higher relaxivity compared with other gadolinium compounds.



MRI angiography
clotting in renal vein, indicated by white arrow

Advantages

- no ionizing and safe
- the main advantage of MRI over CT is that it gives far better contrast resolution (the ability to distinguish the differences between two arbitrarily similar but not identical tissues) and thus its ability to demonstrate changes between normal and pathological tissues
- MRI angiography can produce images in any plane
- MRI angiography can be performed with or without the use of IV contrast materials; this concept is quite beneficial to those patients with severe contrast allergies, as well as those with poor kidney function

Disadvantages

- has been image degradation by patient movement (especially respiration), inability to see distal renal arteries and poor resolution compared with CT
- invasive procedure

16. Image-guided urological interventions

Uroradiological interventions may be broadly classified as ***non-vascular and vascular.***

Non-vascular procedures mainly include tissue sampling (fine needle aspiration or biopsy), percutaneous nephrostomy (PCN) and stone extraction.

Vascular procedures mainly include embolization of pseudoaneurysms, arterio-venous malformations and fistulas most commonly presenting with hematuria. Others include prostate artery embolization (PAE), recanalization of renal artery stenosis (RAS), gonadal vein embolization (varicocele, pelvic congestion syndrome), etc.

Anatomical location, use of iodinated contrast and real-time guidance are the most important factors in choosing a preferred imaging modality.

Patient preparation

Most image-guided interventions are performed under local anesthesia with conscious sedation and analgesia. As a general rule, the INR should be ≤1.5 and platelets greater than 50,000/cu mm for most procedures.

16.1 Non-vascular procedures

1. Tissue sampling

Imaging-guided percutaneous renal biopsy has evolved to become a safe, minimally invasive technique to sample renal parenchyma for the evaluation of malignancy or diffuse renal disease. Current biopsy techniques involve CT or ultrasound guidance with small-gauge needles. The risks of renal biopsy are minimal.

Image-guided urologic biopsies include

- non-focal biopsies
- focal renal biopsies
- renal cyst aspiration
- adrenal biopsy
- transrectal prostate biopsies

a) Non-focal renal biopsy

Indications

- histological characterization of renal parenchymal diseases

- unexplained acute or rapidly progressive renal failure
- nephrotic syndrome and significant non-nephrotic proteinuria
- persistent glomerular hematuria
- systemic diseases with renal involvement
- renal allograft dysfunction.

Procedure

After placing the patient in the appropriate position (supine for transplant and prone or prone oblique with target side dependent for native kidneys), the biopsy needle (15–18 G) is advanced obliquely into the renal cortex near the lower pole. The cortical sample ensures that the specimen contains a few glomeruli necessary to make a diagnosis. Puncture of the renal medulla or renal sinus must be avoided.

Advantages

- information obtained by renal biopsy may confirm, support or eliminate diagnostic probabilities
- results of biopsy may be helpful in formulating prognoses and treatment plans for some diseases
- in some patients, properly performed serial biopsies of the kidney may also be used to monitor therapeutic efficacy, resolution or progression of renal disease

Disadvantages

- can be damage to large vessels resulting in significant hemorrhage or areas of infarction if the corticomedullary junction is crossed
- it is generally unhelpful in cases of glomerular disease and interstitial nephritis

b) Biopsy of renal masses

Indications

- differentiation benign small renal masses from tumors
- differentiation a concurrent renal cancer from a metastasis in known primary extra-renal malignancy

Procedure

Renal mass biopsy may be performed under CT or USG guidance. If the mass is not visible on a non-contrast CT scan, it may be demonstrated following administration of intravenous iodinated contrast. The mass is first approached using a 17 G cannula into which an 18 G coaxial biopsy needle or gun is introduced to obtain several cores. The use of a co-axial system allows multiple samples to be taken by only one puncture of the renal capsule.

Advantages

- renal biopsy with either CT or USG guidance is safe and has a high success rate, with a sensitivity of 70–100% and specificity of 100%

Disadvantages

Following are the contraindications of kidney biopsy:

Absolute

- small kidneys
- abnormal coagulopathy
- uncontrolled hypertension.

Relative

- solitary kidney
- uncooperative patient
- unable to lie flat on bed

c) Renal cyst aspiration

Minimally invasive techniques are currently used to treat symptomatic renal cysts.

Indications

- aspiration is performed to differentiate benign cysts from malignant cysts (renal cell carcinoma RCC)

Procedure

The technique is identical to focal renal biopsies. Aspiration can be coupled with biopsy if the cyst wall has solid nodule(s). Various techniques like injection of water-soluble contrast or air may be used to make such nodules apparent on non-contract CT.

Advantages

- this procedure is highly successful
- cyst aspiration is an easily performed procedure
- it can be done under local anesthesia on an outpatient basis and has low morbidity
- this intervention will eliminate cysts and reduce the size of cysts

Disadvantages

- stricture formation may occur secondary to sclerosing-induced peripelvic fibrosis
- the procedures are complicated by hemorrhage
- ureteral pelvic junction obstruction secondary to stricture formation caused by extravasation of sclerosing agent has been reported
- potential risks for percutaneous renal procedures include extravasation and technical errors

d) Adrenal biopsy

The adrenal glands are an important site of both primary and secondary disease processes. Image-guided percutaneous biopsy of the adrenal gland is an accurate and safe alternative to surgical biopsy.

Indications

Clinical scenarios in which needle biopsy may be indicated:

- include an adrenal lesion in patients with multiple malignancies
- the need for staging a known malignancy
- defining an unknown primary source
- or differentiating benign from malignant adrenal masses with equivocal imaging findings

Procedure

It can be easily performed using CT or sonographic guidance. For the histologic diagnosis of right adrenal masses that are either invisible or inaccessible via the standard extrahepatic route, the transhepatic core route appears to be feasible and safe. CT-guided adrenal biopsy has a high success rate (80–95%).

Image-guided percutaneous biopsy of the adrenal gland is usually performed under CT guidance via an anterior transhepatic/transpancreatic approach, a lateral transhepatic/transsplenic approach or a posterior transpulmonary/transpleural approach.

The ideal body position to carry out biopsy varies from patient to patient. The preferred position is the one that makes the patient more comfortable during the procedure, which in the majority of cases is the prone position. However, in some cases the oblique or lateral position is required to move structures that are in the needle path, such as the lung and inferior vena cava. In the lateral or oblique position, the inferiorly located lung tends to expand less, thereby reducing the risk of pneumothorax. In cases of right adrenal biopsy, in which the inferior vena cava lies on the needle path, the left lateral or oblique position can help to move it and improve access for biopsy.

Advantages

- effective and safe procedure with high accuracy for diagnosis in many clinical settings

Disadvantages

Complications of the procedure may be the following

- hemorrhage
- Infection
- pneumothorax (may be a complication due to its proximity to pleural recess)
- hypertensive crisis

e) Prostate biopsy

A prostate gland biopsy is a test to remove small samples of prostate tissue to be looked at under a microscope. The tissue samples taken are looked at for cancer cells.

Indication

- suspicion of prostate cancer based on abnormal digital rectal examination and/or elevated serum prostate-specific antigen (PSA) levels

Procedure

It is most commonly performed using transrectal ultrasound (TRUS) guidance with the patient in the left lateral decubitus position. For a prostate biopsy, a thin needle is inserted through the rectum (transrectal biopsy), through the urethra, or through the area between the anus and scrotum (perineum).

Advantages

- the TRUS biopsy is definitely more reliable than the prostate-specific antigen (PSA) test

Disadvantages

- hematuria and hematospermia are seen in up to 80% of patients in the first 2 weeks, and are self-limiting
- the TRUS biopsy has a false-negative rate of up to 30%.

2. Drainage procedures

Drainage procedures are either used to divert an obstruction or to drain collections.

a) Percutaneous nephrostomy (PCN)

Percutaneous nephrostomy, or nephropyelostomy, is an interventional procedure that is used mainly in the decompression of the renal collecting system.

Indications

There are four broad indications for the placement of a PCN:

- relief of urinary obstruction
- diagnostic testing

- access for therapeutic interventions
- urinary diversion

Procedure

A posterolateral sub-costal approach targeting the lower (or middle) calyx prevents entering through the pleural recess and permits access through the Brodel's avascular plane of the kidney. A soft tip wire is then inserted into the collecting system and is replaced with a stiff wire using a 6 F fascial dilator. The tract is serially dilated up to 8 or 10 F and a pigtail catheter or Malecot nephrostomy tube is then placed into the renal pelvis. The latter is a better choice if the collecting system is either small or filled with calculi.

Advantages

- PCN has a high success rate, approaching 100%, in dilated systems and around 80% in undilated systems
- it allows decompression of the obstructed system
- permits specimen collection
- creates a route for antibiotic instillation if needed
- this procedure decreases the risk of urosepsis associated with acute surgical intervention
- often, patients may avoid surgery because the obstructing calculus spontaneously passes after the edema within the ureter subsides
- if the obstruction is the result of postoperative edema, percutaneous nephrostomy allows the edema to subside

Disadvantages

Complications include

- bleeding
- infection
- injury to adjacent organs

b) Suprapubic catheter

Indications

- acute and chronic urine retention that cannot be adequately drained with a urethral catheter or where urethral catheterisation is contraindicated
- preferred by patient due to needs for comfort and access to catheter care, such as wheelchair user
- acute prostatitis
- obstruction, stricture, abnormal urethral anatomy
- traumatic injury to lower urinary tract or pelvic trauma
- to minimise complications of long-term urethral catheterisation, such as urethral trauma
- when long-term catheterisation is used to manage incontinence
- complex urethral, abdominal surgery or gynaecological surgery
- faecally incontinent patients who are constantly soiling urethral catheters or experience moisture lesions
- sexually active patients
- neuropathic disorders causing frequent catheter expulsion
- restricted hip mobility, spasticity

Procedure

It may be inserted under ultrasound guidance or even fluoroscopy in a contrast-opacified urinary bladder. A 12 F Foley catheter loaded over a trocar is used to enter the bladder.

A urinary bladder catheter inserted through the skin about 1 inch above the symphysis pubis. It is inserted under a general or local anesthetic. It is used for closed drainage and may be left in place for a time, sutured to the abdominal skin.

Advantages

- it include a lower incidence of urinary tract infection
- ease of voiding naturally when the catheter is clamped

- there is no risk of urethral trauma, necrosis or catheter-induced urethritis and urethral strictures
- greater comfort, particularly for patients who are chair bound as the catheter is not positioned between their legs and there is less risk of sitting on it
- reduced risk of catheter contamination with micro-organisms that are commonly found in the bowel
- easier access to the entry site for cleansing and catheter change
- makes it easier to engage in sexual intercourse than a urethral catheter
- can be blocked off and the ability to void via the urethra assessed before the catheter is removed (trial without catheter, or TWOC)
- micturition is still possible if the urethra is not surgically closed or obstructed;
- evidence of greater satisfaction and quality of life when compared with urethral catheterization

Disadvantages

- hemorrhage, including hematuria and intra-abdominal bleeding
- infection, including UTI and infection of the track site
- pain and possible injury to abdominal organs
- insertion is an invasive procedure that carries with it the risk of bleeding and visceral injury
- the patient may still leak urine via the urethra
- patients with artificial heart valves may require antibiotic therapy before initial insertion or routine catheter changes, although this will depend on local healthcare management policy
- patients on anticoagulant therapy will require coagulation levels to be checked before a suprapubic catheter is inserted

3. Stone management

Ureteric stent

Ureteral stenting help restore urine flow through blocked ureters and return the kidney to normal function.

Indications

Stents may be uses for a short of long-term period depending on the indication:

- obstruction from urolithiasis
- malignant obstruction (typically pelvis malignancies)
- benign strictures
- retroperitoneal fibrosis

Procedure

An antegrade, percutaneous route may be required to place a ureteric stent. The choice of approach (retrograde or antegrade) is based on the accessibility and the location of ureteric pathology.

Advantages

- no external collection device
- low risk of injury
- uncorrected coagulopathy not contraindication
- less urgency for definitive management

Disadvantages

- one end of the stent may migrate or in rare circumstances completely dislodge
- urosepsis following the process of insertion
- failure to insert, typically due to a stricture that is impassable

4. Thermal ablation for renal cancer

It is provide local treatment for renal carcinomas in patients unsuitable for surgery. Patients having renal insufficiency at presentation and tumors requiring a more nephron-conserving approach (solitary kidney, multiple synchronous RCC, von Hippel Lindau/familial RCC) are also candidates for these minimally ablative therapies.

Indications

- renal cell carcinoma of a single or transplanted kidney, when even an organ-preserving operation can disrupt the function of the kidney
- synchronous bilateral primary renal cell carcinoma
- patients with von Hippel-Lindau syndrome, prone to the development of renal cell carcinoma with multifocal growth, for which alternative treatment can only be bilateral nephrectomy followed by dialysis
- unwillingness of the patient or the inability to perform an organ-preserving or organ-bearing operation due to severe physical status

Procedure

An important aspect of the preparation for the intervention is to determine the distance between the tumor and the renal hilum as the local thermal ablation effect may be reduced by heat loss via blood and urine flow close to the target tissue volume (heat sink effect).

Radiofrequency ablation (RFA) and cryoablation (CA) are typically performed under sedation and analgesia. The ablation probe is inserted percutaneously into the target lesion under tomographic guidance. Where bowel is located immediately adjacent to the tumor, a safety distance to the ablation probe can be created by means of hydrodissection. This is achieved by advancing a 20G tap cannula between the tumor and the bowel and then injecting 100–500 mL of 5% dextrose solution or air to create a protective thermal insulation zone.

Advantages

- computed tomography provides accurate localization of the needle applicators, and visibility of the applicators is not limited by treatment effects such as gas formation or small amounts of hemorrhage
- near the end of an ablation, a bolus of contrast material may be useful in demonstrating remaining tumor

- radiofrequency systems allow for electrocautery of the needle tract upon removal

Disadvantages

- tract ablation theoretically limits tract seeding and
- the risk of hemorrhage

5. MR-guided ablation of prostate cancer

Focal ablative therapy of prostate cancer is an emerging therapy that is being investigated for the treatment of localized tumor.

Indications

- treatment of localized tumor

Procedure

Laser ablation refers to the destruction of tissue using a focused beam of electromagnetic radiation emitted from a laser. Other terms for laser ablation include photothermal therapy, laser interstitial therapy, and laser interstitial photocoagulation.

The principle of focal laser ablation therapy is to destroy a tissue target using laser radiation energy. The resulting rapid temperature elevation of the targeted tissue induces protein denaturation, resulting in in vivo tissue destruction. Prostate tissue is well suited for focal laser ablation due to its optical absorption rate without excess vascularity, which allows for finely controlled ablation.

Accurate ablation of the target is accomplished through transperineal or transrectal introduction of a laser fiber into the focal abnormality. Accurate laser fiber localization to soft tissue targets is feasible, and real-time MRI during the ablative procedure allows precise estimates of the extent of tissue necrosis.

Minimal thermal destruction to surrounding tissues and neurovascular structures is achieved through real-time monitoring during the tissue ablation. This can be achieved by proton-resonance frequency (PRF) shift MR thermometry, which allows near real-time quantification of temperature using changes in the phase of gradient-recalled echo (GRE) images to estimate relative temperature changes (ΔT).

Advantages

- it does not involve the use of ionizing radiation
- constant and high-precision temperature monitoring
- clearly marked boundaries between the tumor and surrounding tissues
- evaluation of the result immediately after the procedure
- clear visualization
- the possibility of three-dimensional evaluation of the goal
- takes much less time than surgery

Disadvantages

- the formation of an abscess in the place of tumor necrosis
- bleeding, formation of a hematoma
- reactive inflammation of surrounding tissues
- their infiltration damage to closely located tissues and organs

6. Contrast-enhanced ultrasound (CEUS)-aided renal biopsy

Indications

- acute renal failure (ARF)
- suspicious vascular origin
- suspicious renal lesions

Procedure

CEUS uses stabilized microspheres filled with gas as a new type of ultrasound contrast (sulfur hexafluoride) medium. It enhances tumors and other vascular structures without the use of potentially nephrotoxic iodinated contrast media. Ultrasound contrast is excreted via the lungs and has no serious side-effects. Currently, there is paucity of literature using CEUS-assisted renal biopsy.

Advantages

- CEUS has advantages over CECT and MRI including unmatched temporal resolution due to continuous real-time imaging
- lack of nephrotoxicity

- potential cost savings
- CEUS has been most thoroughly evaluated in workup of complex cystic renal lesions

Disadvantage

- low specificity

16.2 *Vascular interventions*

1. *Endovascular embolization*

It is a minimally invasive procedure where the lumen of the intrarenal vessel is occluded by embolizing material.

Indications

- include persistent hematuria as a result of pseudo-aneurysm
- arteriovenous fistula following a biopsy
- surgical or accidental trauma
- it is also employed to reduce vascularity of renal tumors, e.g. angiomyolipoma or renal carcinoma prior to surgery

Procedure

Vascular access is generally obtained via the common femoral artery with an 18- or 19-gauge puncture needle via a modified Seldinger puncture technique. If the femoral arteries are occluded, an alternative access site such as the axillary or brachial artery can be used. While a 5-French sheath is generally used, a larger caliber sheath may be needed for more complex procedures that involve balloon catheters.

Gel foam and vascular coils are the usual materials used for this purpose.

Advantages

- superselective embolization of the feeding artery saves more functioning nephrons than conventional surgery
- minimal invasiveness
- few early or late complications
- lack of necessity for general or intrathecal anesthesia

- compared with surgical treatment, there is a lower risk of intraoperative blood loss
- fewer local complications such as suppuration
- lower rate of urine extravasation or ureterocutaneostomies
- there is no need for nephrectomy associated with failure of surgical treatment

Disadvantage

Complications include:

- Bleeding
- Infection
- renal arterial injury
- Infarction
- allergic reaction

2. Transjugular renal biopsy

Transjugular renal biopsy (TJRB) is still a novel technique of renal tissue sampling exploiting the transjugular route.

Indications

The procedure is carried out in patients where percutaneous biopsy is contraindicated, usually due to a deranged coagulation profile.

Procedure

A special biopsy needle is wedged into the peripheral renal vein branch via the transjugular route. It provides diagnostic yield and safety similar to percutaneous renal biopsy. It has an added advantage that it allows multiorgan biopsy during the same procedure, e.g. simultaneous liver and renal biopsy.

Advantages

- Its major advantage is to afford histological diagnosis in patients with bleeding disorders or with a compromised background which would preclude percutaneous needle biopsy, or surgical biopsy of the kidney

Disadvantage

- transjugular renal biopsy is time consuming and necessitates occupation of a radiology room, adding to the cost of the procedure

Complications include:

- hematoma
- bleeding

There are cases where transjugular renal biopsy is not feasible for underlying anatomic or morbid associated conditions.

Three pitfalls should be cited here:

1) thrombosis or congenital absence of right internal jugular vein
2) recurrent course of right renal vein
3) thrombosis of the inferior vena cava and/or right renal vein

3. Gonadal vein embolization

Indications

It is performed in males for scrotal varicocele causing pain and infertility and in women for pelvic congestion syndrome as a result of retrograde flow in incompetent ovarian veins, causing chronic pelvic pain. The veins are approached via a jugular or femoral route.

Procedure

After diagnostic angiography, the veins are embolized using steel coils. The clinical outcomes of technically successful percutaneous internal spermatic vein embolization are similar to surgical treatment.

In both-sided varicocele, treatment can be performed in the same session through the same skin entry site. In surgery, two different incisions are necessary.

Advantages

- if the patient has leg varicosities besides the varicocele, both may be caused by the refluxing testicular vein, and if this vein is embolized the both conditions can be treated
- in embolization, there are no incision and stitches. Everything is done through a small hole in the vein
- embolization is performed under local anesthesia while in surgery, general or spinal anesthesia are needed
- after embolization patients may leave the hospital a few hours after the procedure, while in surgery hospitalization is generally required

Disadvantages

- the most important disadvantage of embolization is the unavailability of the technical equipment (e.g. angiography device) and staff (e.g. interventional radiologist)

4. Recanalization of RAS

Indications

- renal arterial stenosis

Procedure

Recanalization involves balloon angioplasty and/or stenting of hemodynamically significant RAS defined by a transstenotic pressure gradient of $\geq$ 20 mmHg. The renal artery is approached via the transfemoral route. Preliminary diagnostic angiography defines the site of stenosis. The stenosis is crossed using a guide wire and balloon angioplasty ± stenting is performed.

Advantages

- stenting, coupled with angioplasty, has a higher success rate

Disadvantages

- the procedure is associated with a significant risk of complications**5.**

Prostate artery embolization

This is a new, minimally invasive endovascular technique to treat lower urinary tract symptoms due to benign prostatic hypertrophy. It is undertaken sporadically in few centers in patients, especially with prostates over 80 g, who are refractory to medication or at high risk for surgery.

Indications

- lower urinary tract symptoms (LUTS) secondary to benign prostatic hyperplasia (BPH)

Procedure

It is performed under local anesthesia as an outdoor procedure with low morbidity and rapid recovery. The prostate arteries arising from the anterior division of the internal iliac artery are super selectively catheterized followed by slow injection of diluted embolic agents. Both polyvinyl alcohol (PVA) (size 100–200 μm) and gelatin microspheres have been used. The end point is identified by near stasis of flow in the injected arteries and gland opacification.

Advantages

- improves quality of life
- preserves sexual function in short- and medium-term follow-up
- may therefore be seen as an effective alternative to surgery

Disadvantages

- paucity of long-term data

6. Renal sympathetic denervation

Is a minimally invasive, endovascular catheter based procedure using radiofrequency ablation or ultrasound ablation aimed at treating resistant hypertension (high blood pressure not controlled by medication). Nerves in the wall of the renal artery are ablated by applying radiofrequency pulses or ultrasound to the renal arteries. This causes reduction of sympathetic afferent and efferent activity to the kidney and blood pressure can be decreased.

Indications

- chronic kidney disease
- resistant hypertension (high blood pressure not controlled by medication)
- heart failure

Procedure

The procedure is performed like renal angiography using the transfemoral route under local anesthesia. A 6 F sheath is placed in the femoral artery through which an electrode-tipped catheter is advanced into the renal artery under real-time fluoroscopic guidance. Once the desired position is reached, the catheter is connected to a RF generator and low-level radiofrequency energy is delivered through the renal artery wall to disrupt the surrounding renal nerves. Simplicity HTN-2 trial involving patients with uncontrolled hypertension showed that this procedure leads to notable and sustained reductions in blood pressure

Advantages

- renal sympathetic denervation presents a major improvement with several significant advantages over the radical sympathectomy
- it is a localized procedure
- minimally invasive
- has no systematic side effects
- the procedural and recovery times are very short

Disadvantages

- patients may experience pain during application of radiofrequency pulses and intraprocedural bradycardia requiring atropine has also been reported
- other documented procedure related complications include femoral artery pseudoaneurysm and renal artery dissection
- risk of damage to renal arteries during delivery of radiofrequency energy

Summary

In summary, there is as yet no one comprehensive best imaging examination for the urinary tract; each has its advantages and disadvantages and their value depends on indications of the study. The 25-year-old pregnant woman with hematuria is quite different from the 75-year-old man with the same symptom, and the issue of which imaging modality is best will vary with these considerations. The physician must combine evidence-based knowledge of the accuracy and utility of various studies with the art of medicine, combining science with finesse to ultimately result in the best possible evaluation and care of the individual patient.

Finally, although the requesting physician should be well informed about the utility, accuracy, strengths, and weaknesses of available tests, the best care, especially in the fast changing field of imaging, is provided by close consultation between the physician and radiologist.

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