

Genitourinary Imaging Techniques

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In the current era of pediatric urology, use of nuclear medicine, ultrasonography, CT, and MRI has been valuable in the identification and management of genitourinary diseases. The characterization of the renal parenchyma did not occur in the past with retrograde pyelography and was limited with intravenous urography. Excellent information about the renal parenchyma and renal function is currently attainable with current cross-sectional imaging techniques that can identify tissue differentiation of lesions, distinguish dilatation of the pelvocalyceal system, and determine margins of the kidney and perirenal space. Invasive angiography is limited in application specifically to vascular diseases, although they are uncommon in childhood. Because of these newer techniques, intravenous urography has lost its position as the “cornerstone” of urinary tract imaging and is used mainly to identify pathologic conditions of the ureters.

The indications for imaging usually depend on the presentation and age of the patient. In neonates the most common indication for an imaging procedure is the follow-up of an abnormality detected during prenatal sonography. **Box 1** lists the more common imaging indications in neonates. The upper urinary tract and bladder can be visualized with sonography at 15 weeks' gestation; the pelvis and corticomedullary differentiation is readily identifiable after 20 weeks' of gestation. Newer transducers applied transrectally or transvaginally demonstrate these normal structures earlier and with better resolution. Prenatal identification of congenital renal abnormalities is not unusual because the incidence of congenital urinary tract abnormality is 2 per 1000 live births. The most common diagnosed abnormality in utero is an enlarged collecting system. Identifying

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Box 1. Indications for genitourinary imaging in neonates

Prenatal sonographic abnormality
Failure to micturate
Abdominal mass
Genetic syndromes
Hypertension
Sepsis
Ascites

a cause early can be difficult (75%–80% specificity). Prenatal misdiagnosis of hydronephrosis, multicystic kidney, transient enlargement of the collecting system secondary to reflux, prune belly syndrome, primary mega-ureter and bowel duplication, physiologic distention, and ovarian cysts are possible. Of the techniques applied to interrogate disease in neonates, sonography and voiding cystourethrography are the most common.

Beyond the neonatal period, imaging is useful in evaluating the cause of abdominal masses and metastatic disease and for screening several syndromes associated with tumor, including nonfamilial aniridia, hemihypertrophy, Beckwith-Wiedemann syndrome, Bloom's syndrome, neurofibromatosis, hypospadias, cryptorchidism, and gonadal dysgenesis. Imaging serves a major role in identifying pelvic masses and characterizing intersex abnormalities. In older children, sonography is used in evaluating urinary tract infection, trauma, hypertension, and systemic diseases. In adolescence, CT and MRI are used more frequently, which is because of changes in physiology, body habitus, and disease conditions.

Imaging modalities*Sonography*

The most important imaging modality used to evaluate the genitourinary system in newborns is sonography. It provides a noninvasive interrogation, does not require sedation, and can be applied at the bedside to newborns who are too ill to be evaluated in an imaging department. This modality is used frequently because of its lack of ionizing radiation and its representation of detailed anatomy without the use of contrast medium. One disadvantage is that its quality depends highly on the skill of the operator. The understanding of developmental anatomy and disease conditions is a requirement for useful clinical information. Likewise, physiologic information can be inferred only indirectly with an anatomic

examination. Sonography has undergone significant technologic improvements, including specific transducers (linear, high resolution), power Doppler, and harmonic imaging. Currently, contrast agents are being developed that may be applied to add a physiologic diagnosis [1].

High-resolution transducers—7.5 to 15 MHz—used to perform neonatal examinations provide excellent anatomic detail. The standard imaging examination identifies the number, shape, size, and position of the kidneys. Renal length, which is determined with comparison to references that relate renal size to patient age and weight, serves as an indicator of pathology and can be used to assess future renal growth. Renal masses in the newborn period are easily identified by sonography (Box 2). The standard images produced with sonography include longitudinal and transverse views. The intrarenal architecture is evaluated for the normal differences in echogenicity of the cortex and medullary pyramids and the detection of calcification in the renal pyramids, cortex, or renal pelvis. An examination of longitudinal and transverse images of the urinary bladder identifies bladder diverticuli, thickened wall, calculi, and tumors. Distal ureteral dilatation and ureteroceles are readily identified. It is possible to detect a posterior urethral valve with abdominal and perineal imaging planes; however, voiding cystourethrography is the definitive diagnostic examination [2,3].

The adrenal glands are routinely visualized with sonography and appear as Y-shaped or triangular structures in the newborn. They are larger relative to the kidney with a hypoechoic cortex that can be differentiated from medulla.

Because of hormonal stimulation, the uterus and ovaries of female neonates are seen clearly with sonography. The uterus demonstrates a bulbous enlarged configuration and sometimes an endometrial stripe. The neonatal cervix is frequently the largest component of the uterine anatomy. The normal vagina shows a mixed echogenic stripe. A newborn with a urogenital sinus or imperforate anus shows a fluid-filled vagina. The neonatal ovaries have follicular cysts and sometimes appear alarmingly large. Because genital anomalies are associated with abnormal urinary tract development, an abnormal urinary tract sonogram must include the interrogation of the genitalia.

Box 2. Sonographic findings of renal masses in neonates

- Urinary tract obstruction
 - Ureteropelvic junction
 - Ureterovesical junction
 - Posterior urethral valves
- Reflux with hydronephrosis
- Multicystic dysplastic kidney
- Nonpolycystic nephromegaly
- Neuroblastic nephroma
- Renal cystic disease

Aplasia and atresia of the uterus and vagina are associated with upper urinary tract anomalies, with unilateral renal agenesis being the most common. With absence of the vagina (Mayer-Rokitansky-Kuster-Hauser syndrome) there is a 15% incidence of renal agenesis and less frequent anomalies, such as ectopia, fusion, and horseshoe kidneys [4]. There are three main causes of vaginal obstruction: (1) imperforate hymen, (2) vaginal septum, and (3) urogenital sinus anomaly. Sonography is useful as one of the components in the complete evaluation. Vaginal obstruction may be the cause of upper urinary tract obstruction. In these anomalies, urinary tract screening with sonography and cystography is essential. There are circumstances in which studies of the vagina with contrast are helpful (vaginography). Uncommonly, complex abnormalities of the urinary tract may require excretory urography or helical CT to identify the position, caliber, and insertion of the distal ureter not visualized with sonography and cystography.

The most complex developmental abnormality of the female genitalia is the cloacal anomaly, in which the urinary tract, reproductive system, and gastrointestinal tract all merge into a single opening of the perineum. In addition to obstruction, urinary tract anomalies such as dilated refluxing ureters, bladder diverticula, urachal malformations, crossed fused ectopia, and renal agenesis can be identified. A complete evaluation of the urinary tract and reproductive and gastrointestinal structures is essential for appropriate surgical therapy [5–7].

The urinary tract is evaluated with sonography in evaluation of disorders of sexual differentiation. Although there are many anomalous components, only female pseudohermaphroditism of nonadrenal origin has been shown to have significant urinary tract developmental anomalies. Most often, however, ovaries, testes, uterus, and cervix can be seen. Ovarian tissue and testis may appear similar in shape and size; however, follicular cysts are present in ovaries and aid in the determination.

In boys, there is a slight correlation between genital and upper urinary tract anomalies. Abnormalities of the penis are best studied with voiding cystourethrography. In cryptorchidism there is a 5% association with significant urinary tract anomalies, especially if associated with hypospadiasm. The evaluation for intersex abnormality should be performed because 25% of patients with hypospadiasm and cryptorchidism are at risk. Sonography is used for screening the kidneys and the genital system in these cases for female structures.

Sonography in newborns is used for evaluating urachal abnormalities, which include patent urachus, vesicourachal diverticulum, urachal cysts, and sinuses. Sonography shows the urachal structure extending from the anterior superior aspect of the bladder coursing a variable distance to the umbilicus. Urachal anomalies can be associated with prune belly syndrome and posterior urethral valves [8–11]. Imperforate anus and the syndrome of caudal regression may have urinary tract abnormalities. Abnormalities ranging from an isolated low, translevator imperforate anus without urinary tract anomalies to the absence of the sacrum and coccyx with imperforate anus and fistulous tracts from the gastrointestinal system to the genitourinary system form the continuum of the syn-

drome of caudal regression syndrome. In general, high imperforate anus lesions are associated with fistulous tracts; the termination in boys frequently is a prostatic urethra, whereas in girls the lesion is associated with the vagina. The incidence of urinary tract anomalies other than fistula in high or intermediate lesions is 50%, whereas it is 5% in low lesions. Sonography is necessary in the evaluation process. In conditions such as prune belly syndrome and megacystis-microcolon-malrotation-intestinal hypoperistalsis syndrome, the sonographic examination reveals the large bladder with, in most instances, hydronephrosis. Neonates who receive calciuric drugs and supplemental calcium are at risk for developing nephrocalcinosis, which is associated with the calciuric effect of the drug. Sonography readily identifies urolithiasis and medullary nephrocalcinosis [12–14].

Hydronephrosis may be secondary to obstructive or nonobstructive disease. The most common site of obstruction of the urinary tract is the ureteropelvic junction. Diagnostically, there are three categories of lesions that result in ureteral dilatation: (1) primary mega-ureter, (2) distal ureteral stenosis, ureterocele, atresia (with a variable functioning kidney), and (3) ectopic ureter with or without a ureterocele. Sonography demonstrates the hydronephrosis and the hydroureter. Real-time sonography can show peristalsis throughout the ureter with or without a to-and-fro character. Although sonography can show duplication anomalies and ureteroceles, voiding cystourethrography and sometimes an excretory urogram are needed to evaluate fully and define the distal urinary tract anatomy.

Moderate neonatal vesicoureteral reflux results in dilatation of the ureter and renal pelvis, which has been observed in utero. At times dilatation is transient and the postnatal examination normal, which demonstrates that dilatation is not always obstructive or pathologic if identified prenatally. On occasion, sepsis can result in urinary tract dilatation in neonates, and ancillary sonographic findings include thickened mucosa caused by edema, abnormal ureteral peristalsis, and sometimes vesicoureteral reflux [15–22].

Multicystic dysplastic kidney (Potter II) is an embryopathy that results from atresia of the pelvoinfundibular region of the kidney. This classic type can be diagnosed easily with sonography. This examination shows multiple cysts of different sizes randomly distributed throughout the kidney that lack communication. An uncommon form exists in which there is atresia of only the ureter and a hydronephrotic type of multicystic dysplastic kidney results. In the hydronephrotic form there is a dominant cyst located in the region of the normal anatomic pelvis. This type has smaller cysts that may communicate with the dominant cyst. There also may be partially functioning parenchyma associated with the smaller cysts. The renal artery is diminutive in both types, and there is a 10% incidence of contralateral abnormalities, the most frequent being ureteropelvic junction obstruction. Other types of congenital anomalies are found in 20% of patients, including congenital heart disease and facial anomalies [23–33].

Neonatal renal venous thrombosis may present with unilateral or bilateral renal enlargement. Various causes include dehydration, decreased renal function and decreased oxygen content, and polycythemia. Renal venous thrombosis is

prevalent in infants of mothers who have diabetes. Although usually a clinical diagnosis, sonography is the best anatomic examination available to establish the diagnosis. Frequently with renal venous thrombosis, the kidney is enlarged with disordered architecture. The normal medullary pyramids are not visualized, and there are random distributed regions of hypo- and hyperechogenicity. The thrombus usually originates in the small, intrarenal venous branches and then propagates into the larger veins. A clot may be seen extending into the inferior vena cava. Doppler evaluation of the intrarenal veins reveals diminished blood flow. Within weeks to months after a renal venous thrombosis, the kidney atrophies. Most often, however, the kidney regains function. In approximately 10% of cases, a reticular pattern of calcification in the walls of the intrarenal veins occurs, which can be demonstrated on CT or standard radiography. Frequently this pattern is identified with sonography in the absence of findings on standard radiographs [34–37].

Nephromegaly is an abnormality in newborns usually defined by an enlarged kidney or kidneys with normal sonographic architecture. The diseases in this group include (1) compensatory hypertrophied kidney secondary to contralateral renal agenesis or hypoplasia, (2) Beckwith-Wiedemann syndrome, and (3) congenital nephrosis. Infants of mothers who have diabetes are also affected. Renal enlargement also occurs secondary to other causes, such as infiltrative disease and inflammation. Beckwith-Wiedemann syndrome is characterized by large body parts combined with macroglossia, omphalocele, diastasis recta, umbilical hernia, and large abdominal viscera. Facial nevi and ear lobe defects also may be present. Thirty percent to 50% of infants who have this disease have neonatal hypoglycemia. These patients are at increased risk for intra-abdominal neoplasms. The kidneys are enlarged in 75% of these children (usually bilateral, but sometimes unilateral). Also occasionally seen with Beckwith-Wiedemann syndrome are medullary dysplasia and medullary sponge kidney. Sonography is used to establish the diagnosis and follow these patients to evaluate for abdominal malignancy, which occurs in at least 10% of patients [38,39].

Solid renal tumors are rare in newborns. The most frequent lesion is the fetal renal hamartoma. The examination reveals a solid tumor with varying degrees of echogenicity. Frequently necrotic regions appear within the tumor. The sonographic pattern of the tumor is indistinguishable from Wilms' tumor and renal cell carcinoma. The age of presentation is usually the key to the histology [40–46].

Several unrelated diseases, syndromes, and conditions may include or cause cysts of the kidneys. In general, most renal cystic diseases in childhood result from renal dysplasia from obstructive uropathy. Sonography should be performed in newborns if renal cystic disease is a clinical concern. The presence of one or two renal cysts does not mean that a patient has polycystic kidney disease, however. The most common cause of nondysplastic renal cysts in neonates is recessive polycystic kidney disease, although dominant polycystic disease may be present.

The pathology in recessive polycystic disease is enlargement of the collecting tubules with cellular hyperplasia. Sonographic examination reveals enlarged

kidneys without ascites. The kidneys show a loss of normal architecture and appear homogeneous but with normal collecting structures. The margin of the kidney is usually hypoechoic. With high-resolution transducers, the appearance of recessive polycystic kidney disease shows minute cysts associated with echogenic lesions of the cortex, which gives a “salt and pepper” or stippled appearance. Liver shows bile duct hyperplasia; eventually, depending on the severity of disease, varying degrees of fibrosis occur in the portal triad. The severity of these hepatic changes is inversely proportional to changes in the kidney. The renal ultrasound appearance of dominant polycystic disease may have similarity to the recessive form but more often has macrocysts in the cortex and medulla [47–59].

In children beyond the age of 2 years, kidney disease may be associated with systemic illnesses, such as pulmonary hemorrhage with glomerulonephropathy, lupus, connective tissue disorders, sickle cell disease, Henoch-Schönlein purpura, bacterial endocarditis, leukemia, and lymphoma. Kidney abnormalities may develop secondary to radiation therapy, toxins, or drugs. Primary renal abnormalities, such as acute poststreptococcal glomerulonephritis, nephrotic syndrome, renal infection, and trauma, commonly occur. Diagnostic imaging serves to demonstrate kidney involvement in these disorders and evaluate complications that may result. Occasionally, renal sonographic findings provide the first clue to the diagnosis of the systemic disease.

In children, the most common cause of acute and chronic hypertension is renal disease. Other causes of hypertension may be categorized under cardiovascular, endocrine, or neurologic diseases and are reviewed elsewhere in this issue. In general, sonography with Doppler and nuclear medicine techniques is the most useful, but CT and MRI are gaining acceptance because of the rapidly developing technology. An important part of the Doppler evaluation is determination of the renal arterial resistance index. The resistive index is defined as the peak systolic flow velocity minus the diastolic flow velocity divided by the diastolic flow velocity. The resistive index is, for the most part, a reflection of resistance to flow into the organ of interest; the closer the resistive index is to 1, the higher the resistance to flow. The resistive index is influenced by vessel compliance, the cross-sectional area of the downstream vascular bed, hydration status, and heart rate. The renal artery resistive index varies somewhat with age. The normal renal arterial resistive index can measure up to 0.9 in preterm infants, between 0.6 and 0.8 in infants and term neonates, and 0.5 to 0.7 in older children [60,61].

The initial imaging technique for the evaluation of a child with suspected renovascular disease is typically sonography. The examination should include careful evaluation of the renal parenchyma for signs of medical renal disease. Asymmetry of the kidneys is an important sign of potential renovascular disease, because the affected kidney is often small and may show signs of scarring. Sonography also serves to exclude urinary tract obstruction or a renal or other retroperitoneal mass. Only rarely can a stenotic lesion in a renal artery be visualized directly with sonography.

Doppler evaluation is an essential component in the sonographic evaluation of a patient with suspected renovascular disease. A renal artery-to-aorta peak systolic velocity ratio of >3.5 is a strong indicator for the presence of renal artery stenosis. The systolic peak of the renal artery waveform may appear flattened. An acceleration time of >0.07 seconds is associated with renal artery stenosis. The tardus-parvus pattern occurs distal to a severe stenosis (eg, the arcuate arteries), which is characterized by slow systolic acceleration and diminished peak systolic velocity. Diastolic flow in the renal artery may be elevated with severe stenosis. The sensitivity of Doppler sonography for the diagnosis of renal artery hypertension in children is unknown. False-negative examination results can occur with mild stenosis, stenosis that involves one or more intrarenal arteries, and stenosis of an accessory renal artery. Further evaluation is indicated if a high degree of suspicion exists [62–64].

Infectious disease of the urinary tract is the most common childhood disease of the urinary tract. Urinary tract infection may involve the bladder or kidneys, or it may be diffuse or focal (acute lobar nephronia, abscess). Infection may be found in congenital anomalies or in obstructed collecting systems (pyonephrosis). Although CT and nuclear imaging can be useful, sonography demonstrates congenital anomalies, pyonephrosis, and perinephric fluid collections. Because of improvements in sonographic equipment, changes characteristic of acute pyelonephritis and abscesses are often seen. Early sonographic findings with acute renal infection include a generalized increase in echogenicity of the parenchyma, an increase in sound transmission, and mild dilatation of the renal pelvis secondary to atony. Sometimes the uroepithelium may appear more echogenic. In a few patients, a reversed pattern is demonstrated; a diffuse increase in echogenicity of the kidneys is demonstrated. The pattern usually reflects a degree of chronicity of parenchymal involvement and the tubular dilatation. Corticomedullary definition is lost when the renal sinus is infiltrated by edema or purulence. A normal sonogram does not preclude an abnormal CT or nuclear medicine cortical imaging because these two modalities are more sensitive than sonography.

There are many approaches to the evaluation of urinary tract in neonates and older children with proven urinary tract infections. The lower urinary tract is evaluated with radiographic cystography. A nuclear medicine cystogram is sensitive in detecting reflux but lacks important anatomic information. If the voiding cystourethrogram produces negative results, sonography is performed to screen for upper urinary tract anatomic abnormalities. If a child has vesicoureteral reflux, a sensitive parenchymal imaging procedure (eg, high-resolution ultrasound or radionuclide cortical scintigraphy) is performed. In neonates, ultrasound (to detect congenital anomalies) and radionuclide cortical imaging may be performed because mild focal changes may be critical in management [65–67].

Voiding cystourethrography

The first description of cystographic techniques to study the bladder and urethra using retrograde filling was described in approximately 1900. The voiding

cystourethrogram, the second most common neonatal urinary tract imaging procedure, is used to evaluate lower urinary tract anatomy. It can be used to distinguish obstructive from nonobstructive hydronephrosis, vesicoureteral reflux, bladder tumors, and ureteroceles. Performed in a fluoroscopic suite, familiarity with catheter size, sterile technique, and the radiation exposure for the examination is mandatory. Newborns and infants must be immobilized. Usually a 5- or 8-F feeding tube is used for catheterization. The examination can be used to calculate bladder capacity and congenital anomalies and determine vesicoureteral reflux. The calculation of bladder capacity for neonates in many institutions is based on a patient's weight.

Some institutions perform cyclic voiding cystourethrograms with two or three cycles of filling and voiding, because neonates void at low bladder volumes and bladder volume influences reflux. A radiograph of the abdomen is performed before the cystogram. Fluoroscopic images are obtained with early bladder filling, and bilateral oblique views are taken with the bladder distended along with images that document the presence or absence of vesicoureteral reflux. A lateral view is frequently obtained at many institutions to identify an occult ureterocele. For a baseline examination, the urethra is imaged and one image of the bladder is obtained. In girls, imaging of the urethra is in the anteroposterior projection, whereas in boys, a steep oblique or lateral projection of the bladder and urethra is obtained. If reflux is demonstrated, a radiograph of the abdomen is obtained after the patient voids to evaluate residual within the bladder and the upper urinary tract.

The 105-mm camera has replaced spot film techniques because of greatly reduced radiation dose to the gonads. Although the 105-mm spot film technique still remains, digital techniques are becoming more available and reduce radiation even further. An approximate 50% dose reduction during voiding cystourethrography occurs when digital spot radiographs are obtained. Another method commonly used to reduce radiation with the digital technique is "freeze frame images" or "last image hold" instead of digital spot radiographs. This technique offers a low-dose alternative in a situation in which high detail is not necessary for a diagnosis, such as follow-up or familial screenings for reflux. Every attempt should be made to keep the dose as low as possible. Fluoroscopic times are less than 1 minute if performed by an experienced pediatric radiologist.

The selection of contrast media for cystourethrography is important. It must be radiopaque and sufficiently viscous to demonstrate bladder and urethral anatomy. It also must be inexpensive, nonirritating, and harmless if introduced into the vascular system or the kidney by reflux. The meglumine salts of diatrizoate and iothalamate are currently the most common agents used [68–73].

The main indication for a voiding cystourethrogram in children is urinary tract infection. The examination is performed to determine whether vesicoureteral reflux or rare congenital anomalies of the lower urinary tract are present. The voiding cystourethrogram is usually performed several weeks after a urinary tract infection has cleared, although it can be performed during acute infection with antibiotic coverage.

Nuclear medicine examination

Diagnostic genitourinary evaluation with nuclear medicine techniques remains an area of untapped potential. The reasons for suboptimal use include physician's lack of knowledge with respect to (1) the diagnostic role and the number of radiopharmaceuticals and (2) inadequate recognition of renal physiologic principles and their relationship to anatomic disease. Appropriate radionuclide imaging techniques provide useful and often invaluable functional information. They also offer the advantages of a low absorbed radiation dose and a significantly lower morbidity compared with what can occur with radiographic contrast procedures.

In the newborn period there is a need for anatomic detail, which outweighs the benefit of lower radiation exposure of the scintigraphic studies. Consequently, radionuclide cystography is not performed in the neonatal period. Its role is in the older child, especially for follow-up examinations.

Cortical renal scintigraphy and diuretic radionuclide renography are used more frequently than excretory urography to assess the upper urinary tract in infants and older children. Tubular transport tracers (eg, technetium ^{99m}Tc mercaptoacetyltriglycine and ^{99m}Tc dimercaptosuccinic acid) identify cortical tissue, and glomerular filtration tracers (eg, ^{99m}Tc diethylenetriaminepenta-acetic acid [DTPA]), are used to evaluate renal function and the upper urinary tract. In general, tubular transport radiopharmaceuticals are preferred over filtration agents in evaluation of the newborn kidney because they exhibit greater first-pass extraction, because neonates have a low glomerular filtration rate. ^{99m}Tc glucoheptonate provides a combination of cortical retention and tubular excretion. As a cortical imaging radiopharmaceutical, 10% of the injected dose remains in the renal cortex for 2 hours. The remainder is eliminated from the kidney through tubular excretion. For these reasons, it is less used in pediatric nephrology and urology.

Dimercaptosuccinic acid is extracted by and accumulates within proximal convoluted tubules but not in the loop of Henle, the renal medulla, or collecting systems. This results in appearance of a rim of cortical activity surrounded by a photon-deficient collecting system. A child is imaged 2 hours after the injection. Multiple projections are obtained: posterior, posterior obliques, and laterals. Pinhole imaging, single photon emission CT, and electronic magnification aid in the interpretation.

Renal cortical imaging with dimercaptosuccinic acid is used to identify congenital anomalies of the kidneys, such as a questionable multicystic dysplastic kidney, or to locate an ectopic kidney not seen on ultrasound. Renal cortical imaging is used to diagnose acute pyelonephritis and renal scarring. Both diseases are demonstrated as regions of absent radiopharmaceutical accumulation (photon deficient). In acute pyelonephritis, decreased accumulation results from the inflammatory edema, which is a response to ischemia and decrease in cellular enzyme function that is necessary for the tubules to bind the radiopharmaceutical. The shape of the kidney is helpful in separating acute from chronic disease. Volume loss is the hallmark of scarring, whereas acute pyelonephritis usually

demonstrates normal renal volume or enlargement. With small cortical defects, it may be difficult to determine whether a defect visualized is acute pyelonephritis or a scar without correlating other images or a follow-up nuclear medicine scan. Once a defect is identified in a kidney it does not mean that it is permanent or progressive. Healing from acute pyelonephritis can occur and is age dependent. In children younger than 1 year, it takes months or longer for the tubular function to recover from pyelonephritis, whereas in older children return to normal or near normal can occur in weeks. This difference may account for the scarring potential in infants [74].

Diuretic renography is performed to evaluate hydronephrosis that may be obstructive or nonobstructive. Diuretic renography is a quantitative examination developed and standardized by the Pediatric Imaging Council of the Society of Nuclear Medicine. The procedure protocol specifies the volume for hydration and the dose and timing of the diuretic, and it requires an indwelling bladder catheter. This procedure, however, is not usually performed in the neonatal period because of reduced renal function and a reduced response to furosemide. Diuretic renography is usually delayed ideally until a child is 6 weeks old. Glomerular filtration rate and effective renal plasma flow increase twofold during this period. Obstructed kidneys may continue to develop, although repair of obstruction is delayed several months, so early scanning may not be important.

Interpretation of the examination includes image interpretation and the evaluation of timed activity curves and quantitative parameters. Because of the standard method used with diuretic renography in pediatric hospitals nationwide, acquisition parameters are similar. The examination identifies patients who do not have obstruction and patients who clearly have obstruction. As with other diagnostic examinations, however, there are pitfalls. For example, if the time it takes to eliminate half of the tracer is between 15 and 20 minutes, the examination is considered "indeterminate" and requires a follow-up. Kidneys also demonstrate decreased washout if they are significantly impaired for reasons other than obstruction, which leads to false-positive results [75–78].

A comparison of this noninvasive radionuclide test with the Whitaker test is limited. Classically, the Whitaker test is performed with percutaneous needle introduction into the pelvicalyceal system using either a single double lumen needle or two needles. One needle/lumen is used to monitor the pressure constantly within the collecting system, and the other is used to infuse a saline/contrast solution. It should be stated that the Whitaker test, which requires a flow rate of 10 mL/sec (an arbitrary figure), measures something different from what is assessed by diuretic renography. Currently the Whitaker test is rarely used in pediatrics. The test is an invasive technique used to obtain information concerning the dynamics of renal collecting system emptying when other studies show pelvicalyceal dilatation. This test is also occasionally useful in patients who have persistent symptoms after surgical repair of ureteral stenosis, because some degree of collecting system dilatation after repair is common despite appropriate relief of the obstruction.

Renal scintigraphy in conjunction with the use of an angiotensin-converting enzyme (ACE) inhibitor, such as captopril, can be helpful in diagnosing reno-

vascular hypertension and can help determine the functional significance of a known renal artery stenosis. Various specific protocols are available for this examination, but most involve renal imaging with and without ACE administration. The scintigraphy can be performed either with ^{99m}Tc mercaptoacetyl-triglycine, which is cleared by tubular secretion, or ^{99m}Tc DTPA, which is excreted by glomerular filtration.

ACE inhibition scintigraphy is not performed in neonates because of low glomerular function rate and often the inability for a sick neonate to be moved for any great length of time. The anatomic disease and its physiologic response do not always correlate with renal artery stenosis. The renal artery must be decreased in diameter more than 50% to cause renin-angiotensin stimulation and the resultant hypertension.

The basis of this test is the effect of the renin-angiotensin system on regulation of renal blood flow. When there is a decrease in blood flow, as in renal artery stenosis, the juxtaglomerular complex responds by releasing renin, which is converted initially into angiotensinogen and subsequently into angiotensin I and angiotensin II, a potent glomerular vasoconstrictor that enhances glomerular filtration. In the presence of an ACE inhibitor, glomerular perfusion is impaired and renal scintigraphy reveals defects in perfusion in the kidney with renal artery stenosis. ACE inhibition scintigraphy is performed either with oral captopril or intravenous enalaprilat (intravenous enalaprilat is preferred). For this procedure, hydration is necessary. A small dose of furosemide, 0.1 to 0.2 mg/kg, is administered to empty the renal pelvis. Because the patient is hydrated and may receive furosemide, a Foley catheter is used to keep the bladder empty. The radiopharmaceutical used for the examination is either DTPA or mercaptoacetyltriglycine-3. When DTPA is used, differential function is reduced on the side of the vascular abnormality. On a mercaptoacetyltriglycine-3 examination, the transit time through the cortex is prolonged and differential function is minimally affected. The kidney develops a pattern of cortical retention of radiopharmaceutical similar to the pattern seen in acute tubular necrosis. ^{99m}Tc mercaptoacetyltriglycine-3 is more sensitive for detecting significant renal artery stenosis than DTPA. If renal artery stenosis is the cause of the hypertension, then the nuclear medicine examination challenge test results with the ACE inhibitor should be abnormal. If the challenge test is normal, a renovascular origin of the patient's hypertension is not likely. If the study results are abnormal with the ACE inhibitor, a baseline study without it must be performed. If the baseline study results were normal, a renovascular origin is highly likely.

CT

Despite the advancement reconstruction technology, CT plays a minimal role in evaluating neonates, with the exception of diagnosis of renal, retroperitoneal, and pelvic masses. The CT examination is limited in neonates because of the

paucity of intraperitoneal and retroperitoneal fat, which requires contrast administration to visualize solid organs and vessels. The small amount of contrast given to a neonate must be measured carefully, and sedation is often required. Fluid-filled loops of intestine mimic the attenuation of solid structures, masses, cysts, or lymph nodes. Consequently, opacification of the gastrointestinal tract with dilute contrast is recommended in certain circumstances. Rectal placement of dilute contrast is occasionally used in the evaluation of a pelvic mass. If calcifications are to be detected, a precontrast sequence of images must be obtained. Most intravenous contrast is injected through a power injector. The imaging begins when approximately 75% of the volume of contrast is administered. Sometimes delayed imaging is necessary to characterize renal lesions. The imaging time is short, and the tissue phase may appear after the imaging is completed.

CT has become an integral part of current diagnostic imaging evaluation of the upper urinary tract in children, excluding neonates. CT represents the most common diagnostic examination in abdominal trauma. Trauma accounts for almost 50% of deaths in children aged 1 to 14 years in the United States [79]. Victims of trauma with significant injury present with hematuria, hypotension, rigid abdomen, or abdominal bruising. The kidneys are frequently involved with trauma to the liver, spleen, pancreas, and duodenum. Incidents involving motor vehicles are the predominant cause; pedestrian deaths are prevalent among children aged 5 to 9 years. Boys are involved twice as frequently as girls; blacks and other minority children in the United States are at increased risk for traumatic injury and death compared with whites.

The urinary tract is the second most common organ system to suffer substantial injury in children. Death caused by genitourinary trauma is uncommon; however, approximately 5% of trauma-related fatalities are caused by genitourinary injuries [80]. Children seem to be more susceptible to major renal trauma than adults [81]. Blunt trauma is the cause of 90% of renal injuries in children, and most cases occur in motor vehicle incidents, vehicle-pedestrian accidents, sports injuries, and assault. Most blunt renal injuries are contusions and require no active therapy [82,83]. Pre-existing renal abnormalities, such as hydronephrosis, tumors, and ectopia, generally are considered to predispose a person to injury; however, the magnitude of the risk is questionable. Most renal anomalies in trauma patients are discovered incidentally during CT studies, without evidence of urinary system injury [84]. The rate of pre-existing renal anomalies in children who present with acute renal trauma is 10% or less [85].

Some renal injuries are caused by rapid deceleration. Because the kidney is relatively mobile within the Gerota space, it may be thrust laterally to impact against the lower ribs or medially against the vertebral column. The major renal vessels also can be injured in association with major deceleration forces caused by stretching as the kidney moves relative to the more securely fixed aorta and vena cava. The intima is most susceptible to stretching injury because it is less elastic than the media and adventitia and leads to dissection, luminal occlusion, or arterial thrombosis. Stretching injury also can cause spasm of the renal artery without a tear of the collecting system. With severe, rapid motion of the kidney,

vascular avulsion can occur. The CT examination for abdominal trauma always requires intravenous contrast material. Some institutions use a minimal amount of gastrointestinal contrast. There are several proposed classifications for renal trauma. The minor injuries include (1) parenchymal contusions without a tear in the capsule, (2) superficial cortical lacerations without extension into the collecting system, and (3) laceration at the fornices, with small parenchymal lacerations that communicate with the collecting system. The major injuries include (1) deep parenchymal laceration with extension from the capsular surface to the collecting system (the capsule may be intact or disrupted and significant subcapsular hemorrhage is present), (2) shattered kidney, in which it is disrupted into multiple fragments with extension into the collecting system and subcapsular surface (the capsule may be intact or disrupted and there is usually a significant perirenal hematoma), (3) vascular pedicle injury with subintimal flap, vascular avulsion, spasm, or occasionally, vascular thrombosis, and (4) ureteropelvic junction avulsion injuries with laceration, which are best categorized on the basis of CT findings.

Contrast-enhanced CT is useful in evaluating intrarenal or perirenal infection, focal bacterial nephritis, and complicated pyelonephritis. Renal cortical scintigraphy, contrast-enhanced CT, and MRI have been used to detect focal pyelonephritis [86–88]. Acute renal infection results in an area of ischemic renal parenchyma and tubular dysfunction. The pathophysiology is such that the injected material does not enter the vascularity of abnormal parenchyma in the same manner as it does in the normal functioning kidney. CT is the superior technique for the characterization of complications, such as an intrarenal or perinephric abscess. Inflammatory edema and microabscesses alter the tissue attenuation characteristics of the infected kidney. Local vasoconstriction and inflammation interfere with contrast excretion in the infected parenchyma. Obstruction of renal tubules with pus may result in retention of the contrast that is excreted. The major CT finding, however, is diminished attenuation on contrast-enhanced images. Various patterns can occur on enhanced images: (1) radially oriented linear streaks of decreased attenuation, (2) round or irregular hypodense foci, (3) wedge-shaped defects, or (4) heterogeneous poor enhancement throughout an enlarged kidney. The nephrogram of the involved kidney is often diminished in intensity. Delayed images frequently show coarse “staining” of the involved parenchyma because of retention of contrast in obstructed tubules, although there is appropriate clearance from the adjacent normal parenchyma. This characteristic is relatively specific to renal infection on CT.

The diagnostic evaluation of urolithiasis with respect to the detection and location of calculi and understanding of the morphology and function of the kidney has changed with imaging technologic advancement. The most significant advancement is the use of helical or spiral multi-slice CT, which provides the highest sensitivity of all diagnostic imaging techniques for the detection of urinary tract calculi. The CT images also should be inspected for evidence of an extrarenal cause of acute flank pain (eg, appendicitis, pyelonephritis, adnexal disease in girls, renal neoplasm) [89].

The most common locations of an obstructing urinary calculus are the uretero-pelvic junction, the pelvic brim, and the ureterovesical junction. On CT, a ureteral calculus almost always can be demonstrated as a high attenuation focus. Other potential findings on CT include dilation of the ureter proximal to the stone, edema in the wall of the ureter adjacent to the stone (the soft tissue rim sign), hydronephrosis, and perinephric inflammation. Occasionally, it may be difficult to determine whether a stone is located in the distal portion of the ureter or in the base of the bladder. Differentiation can be provided with repeat imaging with the patient in the prone position, because a bladder stone falls to a dependent location.

The diagnostic imaging findings in patients with a ureteral calculus can help predict the likelihood of spontaneous passage of the stone. There is a linear relationship between stone size and spontaneous passage; the smaller the stone, the more likely that spontaneous passage will occur. A report that used CT for assessing stone location and size (in adult patients only) determined spontaneous passage rates based on stone diameter as follows: 87% for 1-mm stones, 76% for 2- to 4-mm stones, 60% for 5- to 7-mm stones, 48% for 7- to 9-mm stones, and 25% for stones larger than 9 mm [90]. The more inferiorly the stone is located in the ureter, the greater the likelihood of spontaneous passage. Small stones at the ureterovesical junction nearly always pass spontaneously, whereas only approximately half of stones located in the proximal aspect of the ureter resolve with conservative treatment [91,92].

In consideration of the data concerning spontaneous stone passage, the Ureteral Stones Clinical Guidelines Panel of the American Urological Association recommends the following clinical approach to ureteral calculi [93]. Observation with periodic evaluation is recommended for initial treatment of patients who have newly diagnosed proximal or distal ureteral stones that have imaging characteristics indicating a high probability of spontaneous passage. An alternative approach would be standard radiography of the abdomen to detect calcified urinary tract calculi. Non-contrast-enhanced CT detects calculi in many patients who have normal abdominal radiographs, whereas the converse does not occur. Combined abdominal radiography and sonography may be used for calculus detection in the demonstration of urinary tract obstruction. Sonography is operator dependent and is not as sensitive as CT in the detection of renal stones in children.

Excretory urography

Excretory urography plays a minimal role in the evaluation of the urinary tract in children of all ages. Like CT, reasonable information is not available without intravenous contrast media. Again, the concentrating ability of the neonatal kidney is not developed, and any visualization of the urinary tract is poor. Intestinal gas also makes excretory urography difficult to evaluate.

Preparation of patients is mandatory before excretory urography. Patients must not have anything by mouth for more than 2 hours before the procedure, and adequate intravenous access is necessary. Patients may require hydration before the procedure. A scout radiograph of the abdomen and pelvis is obtained before films with urinary opacification. Most institutions use nonionic intravenous contrast media. The filming sequence frequently involves 1- or 2-minute films and possibly a prone radiograph. Timing is set so that a nephrogram and pyelogram phase is obtained. Currently, excretory urography is usually limited to the evaluation of the ureters if other imaging modalities fail to do so.

MRI

During the last 5 years, MRI has shown great diagnostic capability in older children because of its multiplanar images and the use of intravenous contrast media, which does not depend on compact bolus administration. The paramagnetic contrast agents are tissue-phase agents and do not depend entirely on early vascular opacification for diagnostic information. MRI has a disadvantage, however, because the examination requires a motionless patient and frequently requires sedation. Currently, if cross-sectional imaging is performed, it is more likely that greater information will be yielded from a CT examination in young patients.

MRI basically depicts the distribution of water. It is a multiplanar diagnostic technique that acquires images based on proton density, T1 and T2 relaxation, flow, magnetic susceptibility, and diffusion. Homogeneity of the magnetic field, gradient strength, and magnetic field strength with the use of surface or specifically designed coils to increase signal to noise ratio are applied to produce a diagnostic image. The advantages of MRI include excellent spatial and contrast resolution with multiplanar images. Vascular contrast materials used include gadolinium, Gd-DTPA, a paramagnetic agent that undergoes glomerular filtration, and larger molecular weight agents. Fat suppression techniques are useful in the abdomen, particularly after contrast enhancement by removing the contribution of fat (high signal). The images are degraded in the presence of metallic material and patient movement, including breathing and intestinal peristalsis. The use of surface coils and methods to reduce motion and the development of appropriate contrast agents along with fast imaging times have improved its diagnostic capability in children.

The standard imaging planes are the axial, coronal, and sagittal planes. Skeletal structures are represented as low signal cortex and high signal marrow in older children. Blood within a vessel is identified as a flow void or with vascular contrast enhancement technique. Urine and other water density structures show a long T1 and T2 relaxation time with low signal intensity on T1-weighted and higher signal intensity on T2-weighted scans. Fat shows a short T1 relaxation time, with high signal on T1- and T2-weighted sequences. The kidney has intermediate signal on T1 sequences. The renal cortex has an intermediate signal similar to the spleen, whereas the medullary pyramids show a lower intensity on

T1-weighted images. On T2-weighted scans, the kidney has uniform signal intensity. The renal collecting system and artery and vein are visualized as water and flow voids, respectively. The adrenal glands are readily demonstrated in their superior and slightly medial position relative to the kidney.

MRI is useful for evaluating pelvic structures, including uterus and ovary in girls and testis in boys. The bladder wall is imaged with the low water signal produced by urine. The uterus shows an intermediate signal on T1- and T2-weighted images. MRI is excellent for the evaluation of pelvic structures because of soft tissue contrast, excellent regional anatomic visualization, multiplanar capabilities, and the absence of respiratory degradation. Usually no preparation is required for pelvic MRI.

MRI is valuable in diagnosing intra- and perirenal masses, assessing tissue characteristics, determining affect on surrounding structures, and evaluating neurovascular displacement or invasion. Contrast media is not routinely required in differentiating an intrarenal mass from normal renal tissue. The adrenal gland is better evaluated on CT because of its suprarenal location and horizontal orientation. In the case of a neurogenic tumor, however, MRI is useful for evaluating the relationship of the tumor to the diaphragm, the liver, inferior vena cava and aorta, and the spinal cord. It also visualizes bone marrow disease. MRI of renal tumors identifies the unicentric or multicentric intrarenal origin of the mass, its relationship to adjacent structures, and tumor invasion of the renal vein, inferior vena cava, or pelvis. The uniform intermediate signal intensity characteristics on T1-weighted imaging of Wilms' tumor are interspersed with foci of hemorrhage, necrosis, and cysts. On T1-weighted images these regions are usually of increased signal intensity. MRI demonstrates periaortic lymphadenopathy and liver metastases, which are identified with short repetition time and echo time sequences, or T2-weighted sequences. Simple renal cysts, abscesses, or old hematomas appear on an unenhanced scan as water density. After intravenous contrast, the cyst or hematoma does not change attenuation, but septations within the cyst and the rim of tissue forming the wall show enhancement. Hydronephrosis demonstrates rims of functional renal parenchyma encasing the water density of the collecting system. Besides abscesses, focal infections, such as xanthogranulomatous pyelonephritis or lobar nephronia, demonstrate enhancement with a low attenuating center surrounded by enhancing renal parenchyma.

Infrequent radiologic examinations

Angiography

Vascular stenosis caused by fibromuscular dysplasia results from abnormal overgrowth of fibrous tissue or muscular tissue in the arterial wall. There are six commonly described types of fibromuscular dysplasia. The most common type is medial fibroplasia, which tends to cause multiple focal strictures in the renal artery, alternating with aneurysms. This type produces the "string of beads"

appearance. Fibromuscular dysplasia tends to affect the middle and distal portions of the renal artery. This lesion tends to respond well to balloon angioplasty. Fibromuscular dysplasia is more common in girls [94,95].

Retrograde urethrography

The retrograde urethrogram is a rare procedure in children. A small catheter is introduced into the anterior urethra, and the meatus of the urethra is obliterated. With the patient in a steep oblique projection or lateral position, a small amount of contrast is injected through a syringe for the evaluation of urethra to the external sphincter. Using retrograde urethrography, local systemic complications should not occur with this medium, even in patients with extravasation. The examination is best performed under fluoroscopic control, but if it is not available, a satisfactory study can be obtained with overhead radiography. Retrograde urethrography is not a physiologic examination. Contrast material is often injected under pressure to overcome resistance. Retrograde urethrograms in girls are rarely necessary. This examination is used most frequently to evaluate the consequences of urethral trauma after a straddle injury or pelvic fractures, foreign bodies, or the rare urethral polyp.

Vaginography

A vaginogram is used to evaluate the size of the vagina, a common urogenital orifice, the presence of a cervix, or vaginal mass. The technique is used in cases of ambiguous genitalia or a common urogenital sinus. A small catheter is introduced into the vagina and secured. If possible, another catheter is introduced into the urethra and bladder. Contrast is injected with the patient in a lateral projection. Lateral and oblique views are obtained to establish the relationships of the urogenital structures using fluoroscopy.

Genitography

Genitography is a procedure most often used to evaluate children with suspected intersex or whose sexual differentiation by external genitalia is indeterminate. Most of these children are masculinized girls. Karyotyping is used to determine the sexual chromosome component, and genitography is used to detail the anatomy of the urethra and vagina and the possible presence of a uterus. Genitography is performed by catheterization of the urethra and urinary bladder. After that procedure a second catheter is placed posteriorly. A standard cystourethrogram is performed for the evaluation of bladder and urethra. During this procedure, there may be reflux of contrast material into the vagina that enters a masculinized urethra. If it does not occur, use of the second posterior catheter is helpful. Injection by hand into the urethra with the tip of the catheter placed in the posterior urethra also often delineates a vagina and its associated cervix. These studies are performed in fluoroscopy in the lateral projection. Ultrasound

or MRI may be valuable in establishing the presence of uterus and gonads and the anatomy of the phallus.

Retrograde pyelography

This procedure is usually performed as an adjunct to cystography by a urologist, who places the retrograde catheters into the ureter. Most often the procedure is performed in surgery. The examination is most often used in children with congenital anomalies (blind ending ureter, a duplex or single kidney). After placement of the urethral catheter by the urologist, sterile contrast media is injected carefully and multiple views are obtained to identify anatomic relations of the ureter, renal pelvis, and bladder.

Vesicostomy study

In children with a simple vesicostomy, a small Foley catheter is inserted into the bladder through the stoma. The balloon is inflated and used to occlude the vesicostomy site. A cystogram is then performed by filling the bladder by gravity introduction of contrast. This procedure is performed to evaluate various postoperative conditions.

Nephrostomy and ureterostomy studies

These examinations are performed by gravity introduction or low-pressure manual injection of iodinated contrast material into an indwelling catheter or through a small catheter inserted into the stoma with the tip advanced to the desired location. Both procedures are performed with fluoroscopic guidance. These studies are requested by the urologist to detail postoperative anatomy.

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