The Pediatric Urinary Tract and Medical Imaging

Steven M Penny, MA, R.T.(R), RDMS

After completing this article, the reader should be able to:
- Describe the anatomy and physiology of the urinary tract.
- Discuss typical fetal development and congenital malformations of the urinary tract.
- Describe the various solid tumors that can be discovered when imaging the pediatric urinary tract.
- Describe the etiology and treatment of urinary tract infections and vesicoureteral reflux disease.
- Explain the role of medical imaging in diagnosing pediatric urinary tract conditions.

Renal diseases are a primary cause of morbidity and mortality in children, and urinary tract infections (UTIs) are second only to respiratory infections as the most common bacterial infections in young children. In addition, many pediatric conditions and diseases arise during fetal development, and urinary tract conditions in children can require accurate medical history and laboratory and imaging studies for diagnosis. It is estimated that a child in the United States will receive 7 diagnostic imaging examinations by the age of 18, and the most common type of examinations involve conventional radiography (84.7%) and computed tomography (CT, 11.9%).

Radiologic technologists should understand urinary tract health and diseases so they can optimize medical imaging and as low as reasonably achievable (ALARA) principles.

Anatomy and Physiology

The urinary tract is divided into upper and lower portions. The upper urinary tract consists of the paired kidneys and ureters, and the lower urinary tract includes the urinary bladder and urethra (see Figure 1).

The comma-shaped kidneys are concave medially and convex laterally. Each kidney consists of an upper or superior pole, midportion, and lower or inferior pole. They are retroperitoneal organs, located toward the posterior aspect of the body and adjacent to the spine bilaterally. The bulky liver occupies most of the body's right upper quadrant, leading to the right kidney's slightly lower position in the body compared with the left kidney. The right kidney is bordered anteriorly and inferiorly by the right lobe of the liver.

Atop the right kidney is the right suprarenal gland, also referred to as the adrenal gland. The hepatic flexure of
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dynamically reabsorb amino acids, ions, glucose, and water. The functional unit of the kidney is the nephron, a complicated group of microscopic pipes and sieves composed of specialized cells that help sustain homeostasis by filtering blood (see Figure 2). At birth, each kidney is made up of more than 1 million nephrons. Each nephron moves filtration products from an area of high concentration to an area of low concentration, a function that leads to the creation of urine. Nephrons work so efficiently that by the time filtration is complete, urine comprises elements that are essentially toxic or of no physiological use to the body, such as urea, ammonia, bilirubin, and drug components. The kidneys filter the body’s entire blood volume approximately every 40 minutes, returning 99% of the blood volume to systemic circulation and excreting only 1% of the volume. Of the 1% excreted, the evacuated urine consists of 95% water and 5% nitrogenous waste and inorganic salts. The management of blood volume, paired with the production of the enzyme renin by the kidneys, acts as the body’s blood pressure regulator as well. Other hormones are produced by the posterior pituitary gland, adrenal cortex, and the kidneys to maintain homeostasis (see Table 1). Their production is stimulated by blood volume or oxygen levels.

The kidneys are vital organs, and several surrounding soft and hard tissue structures protect them from injury. In some individuals, the lower ribs partly guard the kidneys, which typically are situated between the 12th thoracic and 4th lumbar vertebrae. The kidneys’ posterior location within the body further protects the organs by proximity of several muscles, specifically the psoas, transversus abdominis, and quadratus lumborum. The kidneys also are surrounded by several layers of fat and a layer of connective tissue called the renal fascia or Gerota fascia. The bilateral adrenal glands also are covered by Gerota fascia.

Each kidney comprises 2 primary parts, the renal parenchyma and the renal sinus. The parenchyma is the functional portion of the kidney, and the sinus houses the collecting system. The fundamental roles of the kidneys are to filter blood, excrete metabolic waste, and the colon is located anterior to the right kidney. On the other side of the body, within the left upper quadrant, the left kidney is capped by the left adrenal gland, which rests slightly anterosuperiorly and medial to the upper pole of the left kidney. Also anterior to the left kidney are the spleen, splenic flexure of the colon, and tail of the pancreas.

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Blood pressure regulates the glomerular filtration rate (GFR) within the nephron. The glomerulus, which is surrounded by the Bowman capsule, is a group of capillaries that forms the basic filtration unit of the kidney. Tubular reabsorption, a function of the nephron in which solutes useful for the body are reabsorbed into the bloodstream, requires 6% of the body’s total at-rest calorie consumption. GFR is a helpful index to evaluate kidney function because it measures the amount of plasma filtered across the glomerular capillaries and then correlates the information with the kidneys’ ability to filter fluids and other substances.

The inner portion of the kidney, called the sinus, accommodates the collecting system, renal vasculature, and lymphatics. Before completely exiting the kidney, urine passes into several channels and temporary storage areas within the sinus. After it moves from the nephron, the fluid passes through the minor calyces. The term calyx, singular for calyces, has a Greek origin that means “seed pod, husk, or outer covering.” The minor calyces give rise to the major calyces and then the renal pelvis. The minor calyces and renal pelvis are located within the renal hilum. The hilum also is the location of the chief renal vein and the renal artery.

Gravity pulls the urine into the bilateral ureters, which are tubular structures 2 mm to 8 mm in diameter and measuring between 8 inches and 10 inches (20.3 cm and 25.4 cm) in length in adults. The ureter and renal pelvis join at the ureteropelvic junction. Urine moves into the bladder through gravity and peristalsis, a series of involuntary contractions. The ureter narrows slightly in 3 areas, which can be susceptible to obstruction. These areas include the:

- Ureters’ entrance to the bladder.
- Point at which the ureters cross the iliac blood vessels.

The ureter meets the bladder at the ureterovesical junction. At this intersection, the ureterovesical valves, which help regulate urine flow, control the release of urine into the bladder and prevent retrograde flow of urine from the bladder to the ureter.

Positioned in the pelvis posterior to the pubic bone, the urinary bladder is a hollow, muscular organ that provides temporary storage for more than 2 cups of urine in adults. The bladder’s muscular wall acts much like a balloon; when the organ is empty, the wall is thick, and as the bladder fills with urine, the wall becomes distended and thinner. Bladder emptying is controlled by the somatic, or voluntary, nervous system in concert with both the sympathetic and parasympathetic parts of the visceral nervous system.

The paired ureters, which ordinarily connect inferior and posterior to the bladder, help to form an area at the level of the bladder neck referred to as the trigone. The third component of the trigone is the urethra, through which urine exits. The internal urethral sphincter relaxes and allows urine to exit the bladder and enter the urethra. The urethra is a cylindrical structure that varies in length according to sex and the individual. The male urethra, which passes through the center of the prostate, can be 16 cm longer than the female urethra. Because the male urethra is so much longer, men are less likely to complain of lower UTIs than are women.

At the distal end of the urethra, the external urethral sphincter facilitates the final evacuation of urine from the body.

### Embryology and Fetal Development

The genitals and the urinary tract develop at the same time in the fetus; these 2 systems often are grouped and referred to as the genitourinary or urogenital system. The embryonic period, which lasts from the point of fertilization through the eighth week of gestation, is a crucial and dynamic period of human development. By the eighth week, most organ systems,
including the urinary system, are in place and somewhat functional (see Figure 3).4

The urogenital system develops in 3 stages: pronephros, mesonephros, and metanephros. A group of cells referred to as the urogenital ridge lies adjacent to the primitive aorta of the embryo and has 2 parts: the nephrogenic cord and the gonadal ridge.4 The cells that make up this ridge develop the pronephros, which is the primordial nonfunctional kidney, along with the mesonephros and metanephros.

The first functional kidney unit, the mesonephros, is present as early as the fourth week of gestation.5 By the end of the fifth week, the metanephros is in place, and the structure eventually evolves into the fully formed adult kidney.4 However, the metanephros is not fully functional until the end of 8 weeks of gestation, and begins producing urine between 11 and 13 weeks.5,6,13 As they develop, the metanephric kidneys lie deep in the pelvis of the embryo, but as the embryonic abdomen grows, the kidneys ascend to their correct position by 12 weeks gestation.13 Each kidney initially begins as a separate body of tissue referred to as a renunculus, but the renunculi progressively fuse over the course of gestation.14 The paired ureters form from the metanephric ducts around the same time as the kidneys.6

Draining of the embryonic kidneys is performed by the mesonephric ducts, also referred to as the Wolffian ducts.6 Lateral to the mesonephric ducts are the paramesonephric or Müllerian ducts. At this point in gestation, the sex of the fetus plays a vital role in the appropriate development of the urogenital tract. In the male fetus, the mesonephric ducts eventually form most of the male genital tract, and the paramesonephric ducts degenerate. In the female fetus, the paramesonephric ducts form most of the female genital tract, and the mesonephric ducts degenerate. In either situation, remnants of the degenerated ducts can persist.6

Early in development, the embryo has a solitary opening shared by the urinary and alimentary tracts, a structure referred to as the cloaca. The ventral portion of the cloaca is the urogenital sinus. The urinary bladder, which is formed by the allantois, the fetal yolk sac, and the upper part of the urogenital sinus, develop early in the fourth week of gestation.4 The lower parts of the urogenital sinus develop into the urethra.4

Figure 3. Gestational development of the urinary system.
In childhood and adulthood, the kidneys are dynamic organs that help sustain life. For the fetus, kidney development and function is even more crucial. From the end of the first trimester, the fetal kidneys continually produce urine. Urine is primarily an excretory by-product of renal function in postnatal life, but the formation and excretion of urine is vital for the developing fetus. For example, most amniotic fluid is made up of fetal urine, and the fluid is essential for the developing fetus. Amniotic fluid helps protect the fetus from trauma, permits symmetric and regular growth of the musculoskeletal system, and is important for gastrointestinal and pulmonary system expansion. Specifically, ingestion of amniotic fluid is essential for human growth and development. Swallowing allows the fetus to absorb the fluid, which is filtered in the fetal kidneys.

The process of fetal swallowing and voiding provides a balance that is necessary for appropriate fetal growth. About midway through the pregnancy, the fetus swallows amniotic fluid at a rate of 4 mL to 11 mL and excretes 7 mL to 14 mL of urine in 24 hours. Consequently, the assessment of kidney function in utero is based partly on amniotic fluid volume. Oligohydramnios, a state of amniotic fluid volume lower than expected for gestation period, can occur because of congenital anomalies of the fetal urinary system.

**Congenital Anomalies**

Congenital anomalies of the urinary system have been observed in up to 10% of the population. Use of medical imaging can help clinicians discover a congenital anomaly of the urinary tract at birth or even before birth. Anomalies typically begin as maldevelopment of the fetal kidneys in number, position, or fusion. Urinary system anomalies constitute 25% of all malformations diagnosed in utero with sonography. This makes the urinary tract the third most common system subject to congenital anomalies; most diagnosed anomalies occur in the central nervous system, followed by the cardiovascular system.

Several forms of renal cystic disease, some of which are inherited, can be diagnosed in a fetus or with postnatal imaging (see Table 2). Inherited renal cystic disease can be autosomal dominant or autosomal recessive. Autosomal dominant disorders can occur in a child when one parent has the genetic alteration, regardless of whether the other parent carries it. An autosomal recessive disorder occurs in offspring only if both parents carry the genetic alteration. A relationship between some forms of renal cystic disease and anomalies of other body systems is referred to as the VACTERL association, for vertebral, anal atresia, cardiac anomalies, tracheoesophageal fistula or esophageal atresia, renal anomalies, and limb anomalies. The VACTERL association demonstrates the link between the associated abnormal development found in these systems. Examples of anomalies that might be present with renal cystic disease include cardiac ventricular septal defects, hemivertebra, and radial hypoplasia.

Congenital malformations should not be confused with inherited renal cystic disorders and anatomic anomalies, the latter of which typically are of little clinical significance (see Box 1). Some congenital malformations of the urinary tract are fatal in nearly all cases.

**Renal Agenesis**

The most severe form of kidney maldevelopment is failure to form both kidneys, a disorder referred to as bilateral renal agenesis. Bilateral renal agenesis occurs in 0.02% to 0.04% of live births. Because the kidneys create most of the amniotic fluid, the absence of fetal kidneys dramatically affects amniotic fluid production, causing the fetus to experience complications such as underdevelopment of the lungs and neonatal renal failure, both of which are impairments that lead to fetal or neonatal death.

Fetuses affected by bilateral renal agenesis have abnormal facial features secondary to compression within the nondistended amniotic sac, a condition known as Potter syndrome. In 2013, a newborn who initially received a diagnosis of renal agenesis survived birth. Once the fetal diagnosis was established using sonography, physicians began to inject fluids around the fetus. The fluids simulated amniotic fluid so that
increasing the likelihood of renal failure. One retrospective study found that of 51 patients with unilateral renal agenesis, 24% had other urological anomalies including ureterovesical junction obstruction, vesicoureteral reflux, and bladder dysfunction. Unilateral renal agenesis also has been associated with anomalies of the heart, vertebral column, long bones, hands, genitalia, and anus.

### Congenital Hydronephrosis

Congenital hydronephrosis is the dilatation of the renal collecting system at birth and accumulation of fluid (see Figure 5). Hydronephrosis has been described as pelviectasis, caliectasis, and pelvocaliectasis, depending on the location of the obstruction or residual fluid. Pelviectasis, or pyelectasis, refers to the dilatation of the renal pelvis, and caliectasis refers to the dilatation of the renal calyces. Pelvocaliectasis is the dilatation of both the renal pelvis and calyces. Pelviectasis is one of the most common fetal kidney abnormalities, with an incidence rate of up to 5%. The condition leads to repeat obstetric sonograms and often to postnatal follow-up imaging in newborns. Because pelviectasis is a common fetal abnormality found on sonography,
it can be an indicator for other chromosomal anomalies. The most common cause of congenital hydronephrosis is a ureteropelvic junction obstruction. The disorder likely is caused by abnormal smooth muscle development in the area of the ureteropelvic junction, although other causes, such as adhesions and bands, have been suspected. Most congenital hydronephrosis is diagnosed prenatally, but occasionally a pediatric patient has a palpable abdominal mass, flank pain, hematuria, or evidence of a UTI. A ureteropelvic junction obstruction is noted on imaging by dilatation of the renal pelvis. More substantial obstruction can result in pelvocalyctasis and possible renal rupture with resultant dysplasia. Ureteropelvic obstruction most often affects the left kidney. Treatment of congenital hydronephrosis includes pyeloplasty or endourological repair.

Other Congenital Anomalies

Other congenital anomalies of the kidneys include renal ectopia, horseshoe kidney, renal hypoplasia, supernumerary kidney, and duplication anomalies. An ectopic kidney, or renal ectopia, typically results from the arrested ascension of the kidney as it moves from the pelvis to the renal fossa. The failure of the developing kidney to ascend to its final location in the upper quadrant sometimes is referred to as a pelvic kidney. Ectopic kidneys also have been discovered in the thorax, however. Ectopic kidneys located in the pelvis typically lead to increased incidence of vesicoureteral reflux, infection, obstruction, and stone formation. In crossed ectopia, both kidneys are on the same side of the body. In nearly 90% of cases, these kidneys also are fused; this condition is called crossed fused ectopia.

Renal fusion, also known as horseshoe kidney, occurs in nearly 1 of every 400 live births. In this condition, the lower poles of the kidneys are fused, resulting in a bridge of renal tissue, or an isthmus, that traverses the midline of the body connecting the 2 kidneys (see Figure 6). The horseshoe kidney has been associated with an increased risk of stone formation, hydronephrosis, and infection, as well as aberrations of other
systems, such as the cardiovascular, skeletal, and gastrointestinal systems, in one-third of affected individuals.\textsuperscript{9,14} Horseshoe kidney also increases the risk for the development of childhood renal cancers.\textsuperscript{14} A rare type of horseshoe kidney, in which both the upper and lower poles are fused, is called the \textit{pancake kidney}.

Renal hypoplasia is underdevelopment of the kidney, resulting in a kidney at birth that is smaller than expected and has functional constraints (see \textbf{Figure 7}).\textsuperscript{23} Renal hypoplasia has been linked with fetal alcohol syndrome and intrauterine cocaine exposure. However, renal hypoplasia also can occur as the result of complicated vesicoureteral reflux disease in children.\textsuperscript{13} Renal hypoplasia should be distinguished from the rare circumstance of a supernumerary kidney, in which a third, or even fourth, underdeveloped kidney is present.\textsuperscript{23}

Duplication of the renal collecting system is the most common congenital anomaly of the urinary tract, with an incidence of 0.8% to 5%.\textsuperscript{14} Duplication can be partial or complete, but partial duplication is more common, accounting for more than 95% of duplication anomalies.\textsuperscript{14} Partial duplication also is referred to as \textit{incomplete duplication}. In this situation, there are 2 separate renal collecting systems and 2 ureters situated one on top of the other, separated by a band of renal parenchyma. The 2 ureters exiting the systems unite somewhere along their route toward the bladder before entering the trigone. Thus, partial duplication results in a bifid ureter, or fissus, that drains classically, producing no clinical complaints.\textsuperscript{27}

Complete duplication of the collecting system also can be referred to as a \textit{duplex kidney}, and it typically consists of separate upper and lower pole collecting systems (see \textbf{Figure 8}). Often, these poles are referred to as the \textit{upper moiety} and \textit{lower moiety}.\textsuperscript{14} A duplex kidney typically is unilateral and found most often in women.\textsuperscript{16}

The Weigert-Meyer law is used to predict the draining patterns of the coexisting ureters in complete duplication.\textsuperscript{28} The law states that the ureter that drains the upper moiety commonly is prone to obstruction, whereas the lower moiety is prone to reflux. The upper moiety is prone to obstruction because of the irregular insertion of the ureter into the bladder, a condition known as an \textit{ectopic ureter}. This obstructed ureter frequently results in a ureterocele, a dilatation of the ureter into the bladder.\textsuperscript{28} Furthermore, with complete duplication, the ureter that drains the lower moiety inserts into the trigone, although it is located lateral and superior to the upper ectopic ureter and runs more perpendicular at the insertion point rather than at the typical oblique angle. This type of insertion predisposes the ureter to reflux.\textsuperscript{14,16,28}

Congenital variants of the ureters, bladder, and urethra also occur. The congenital megaureter is a ureter...
Vesicoureteral reflux also is discovered in 72% of boys with posterior urethral valves. These valves typically are surgically corrected when discovered and can be treated with vesicotomy or valve ablation, but long-term renal impairment remains a persistent concern for most patients and routine clinical assessment is warranted.

Solid Tumors
Several solid tumors in the pediatric urinary tract can be discovered by imaging. These include angiomyolipoma, Wilms tumor, and neuroblastoma. Although angiomyolipomas are benign, both Wilms tumors and neuroblastomas are malignant lesions.

Angiomyolipoma
An angiomyolipoma also is referred to as a renal hamartoma. It is a benign renal tumor that comprises blood vessels, muscle, and fat. An angiomyolipoma is rarely a solitary lesion in the pediatric patient. When multiple angiomyolipomas are identified in infants and children, they most often are associated with tuberous sclerosis. In fact, 80% of patients with tuberous sclerosis have bilateral angiomyolipomas.

Tuberous sclerosis is an autosomal dominant disease characterized by the manifestation of benign tumors in multiple organs including the brain, skin, and kidneys. Tumors found in the brain can result in seizures. On CT scans, an angiomyolipoma appears as a hypodense lesion, and on ultrasonography, the lesion appears hyperechoic (see Figure 8). On T1-weighted magnetic resonance (MR) scans, an angiomyolipoma appears hyperintense. Typically, no clinical treatment is necessary for these small renal tumors, but angiomyolipomas larger than 4 cm might require embolization to reduce the likelihood of complications such as rupture and hemorrhage.

Wilms Tumor
A nephroblastoma, or Wilms tumor, is the most common renal malignancy in children. It accounts for nearly 90% of all pediatric renal malignancies, and constitutes 8% to 10% of all neoplasms in children. Wilms tumor most often is discovered before a child is 5 years old. Patients typically have a large, palpable mass averaging 12 cm at the time of diagnosis,
hematuria, hypertension, and possibly fever.\textsuperscript{14,19} Because of the fever, these patients often present to the imaging department for urinary tract ultrasonography, or a voiding cystourethrogram (VCUG) to be evaluated for possible vesicoureteral reflux. A Wilms tumor often is discovered as a result of imaging for suspected vesicoureteral reflux.

Several syndromes predispose a patient to Wilms tumor. Among them is Beckwith-Wiedemann syndrome, a multiorgan pediatric disorder that includes findings such as gigantism, macroglossia (enlarged tongue), and omphalocele.\textsuperscript{34} These children also are predisposed to malignant hepatic tumors.\textsuperscript{34} Routine screening of high-risk pediatric patients, especially with ultrasonography and CT (see Figure 10), often is warranted to identify tumors early; however, sonography is the modality of choice for screening.\textsuperscript{14,19} There is a 95\% 2-year survival rate for children who have masses confined to the kidney, although distant metastasis produces a much poorer prognosis.\textsuperscript{19} The imaging features of the mass are unique. On a sonogram, the mass appears large and echogenic with distinct borders demarcated well with color Doppler (see Figure 11).\textsuperscript{14} MR images of Wilms tumors reveal low signal intensity on T1-weighted images and high signal intensity on T2-weighted images.\textsuperscript{19} Treatment for Wilms tumor might include surgical resection and chemotherapy.

**Neuroblastoma**

A neuroblastoma is the most common abdominal malignancy in newborns.\textsuperscript{35} A common abdominal location for a neuroblastoma is the pediatric adrenal glands. As with a nephroblastoma, a neuroblastoma might be discovered incidentally during investigation of the urinary tract for other disorders such as vesicoureteral reflux. Patients might present with a palpable mass or pain, but some masses secrete hormones that contribute to varying clinical manifestations.\textsuperscript{36}

Metastasis is seen in approximately 65\% of cases at initial diagnosis; the most common locations for metastasis are the bone, lymph nodes, and possibly the liver or lungs.\textsuperscript{35} Sonographically, a neuroblastoma typically appears hyperechoic, and on CT shows evidence of calcification in approximately 85\% of cases with attenuation similar to or less than that of muscle.\textsuperscript{36} MR images demonstrate low T1-weighted signal intensity with markedly elevated T2-weighted signal intensity.\textsuperscript{36} The primary treatment for neuroblastoma is surgical excision and chemotherapy, although in as many as 10\% of children, the tumor can regress spontaneously with minimal therapeutic intervention.\textsuperscript{36}
Urinary Tract Infections and Vesicoureteral Reflux

Urinary tract infections are common in children, particularly when a child has an underlying anomaly such as vesicoureteral reflux or a voiding problem. Typical renal function is vital for homeostasis and overall quality of life. Consequently, the assessment of renal function must be quantifiable and accurate because early recognition and treatment of obstruction or infection can prevent long-term sequelae. Renal imaging can be necessary to the diagnosis for children with chronic infections and underlying conditions that cause serious complications.

Laboratory tests for pediatric patients primarily are concerned with the discovery of significant bacteriuria or evidence of white blood cells in the urine, definitive signs of a UTI. A urinalysis can provide a global assessment of overall renal function if other renal diseases are suspected.

Obtaining a sterile urine sample in infants younger than 24 months typically requires catheterizing the infant or performing bladder puncture. Catheterization results in a false-positive rate of less than 2% and appears to be the most effective means to obtain a urine sample in children who are not toilet trained. Conversely, bladder puncture, also referred to as suprapubic aspiration, avoids perineal contamination and is highly accurate, although surgical competence is required and imaging assistance typically is warranted. The clean-catch method is recommended for older children who are toilet trained.

In the clean-catch collection method, steps are taken to sterilize the hands, skin folds, and any other possible contaminants to ensure a clean urine specimen. The patient also places the specimen collection cup into a well-established urine stream.

Urine samples can be tested quickly and effectively in the outpatient setting with a dipstick. The dipstick urinalysis provides evidence of leukocyte esterase or nitrite, which indicate infection. Microscopic evaluation of urine cultures also can be performed. The culture is evaluated for bacteria and white blood cells in the sample, both of which are signs of infection.

UTIs are common in the United States, accounting for 8 million office visits and 1.5 million hospitalizations. The urinary tract is considered a sterile environment, and regular voiding defends against invading and accumulating microorganisms. Children who have kidney malformations, such as a duplex collecting system, can have abnormal urine flow, retained urine after voiding, reflux, or a combination of problems. Nearly 8% of girls and 2% of boys have a UTI before the age of 8 years. The risk of recurrent UTI in children in the first 6 to 12 months following an initial UTI has been estimated to be as high as 30%. The overwhelming majority of these infections in girls are the result of bacteria from the perineum that migrate into the bladder via the urethra. The risk is 10 times higher for UTI in boys who have not been circumcised compared with boys who have and is secondary to the entrapment of bacteria in the foreskin.

Although other bacteria can cause UTIs in the pediatric patient, Escherichia coli is implicated in nearly 80% of cases. Other infectious organisms known to cause UTIs include Streptococcus, Enterococcus, and Klebsiella. Most UTIs are considered ascending, meaning that the infection begins in the lower urinary tract with a propensity to move to the upper urinary tract if not treated. Therefore, the bacteria irritate the urethra initially, resulting in urethritis. From the urethra, the bacteria can move into the urinary bladder, subsequently inflaming the bladder and resulting in cystitis. Pediatric patients with cystitis complain of decreased bladder capacity and an urgency to void. If recommended treatment is ignored or ineffective, the infection can move from the bladder to the ureters or

Figure 11. Sonogram of a large nephroblastoma (Wilms tumor) noted in the left upper quadrant of this pediatric patient. Image courtesy of the author.
lymphatic channels and then to the kidneys. Once in the kidneys, the infection can cause acute or chronic pyelonephritis.\(^4\)

In the early 20th century, before the advent of effective antibiotic treatment for febrile pediatric UTIs, the risk for death in children from acute pyelonephritis was approximately 20%.\(^3\) The primary complication of a febrile pediatric UTI is renal scarring, occurring in 15% to 30% of children younger than 4 years. The presence of fever increases the probability of kidney involvement and the risk for renal scarring.\(^3\)

Up to 10% of children have scarring in one or both kidneys following their first symptomatic UTI.\(^4\) One study using intravenous pyelography concluded that scarring in boys is caused mostly by congenital dyplasia; in two-thirds of girls with scarring, the cause was considered to be a UTI.\(^7\) Scarring of the renal parenchyma can lead to adult hypertension (23%), end-stage renal disease (10%), and toxemia during pregnancy (13%).\(^4\) Therefore, treatment for children with a UTI typically is an aggressive medical or surgical approach that includes an investigation of possible sources of infection such as ruling out vesicoureteral reflux.\(^3\)

Vesicoureteral reflux is diagnosed with relative frequency and is the most common heritable disease of the genitourinary system.\(^4\) The retrograde flow of urine disrupts the typical flow but does so in the usually sterile environment of the urinary tract.\(^14,50\) However, reflux can cause infectious bacteria in urine to ascend from the bladder to the kidney. Vesicoureteral reflux can be graded based on the International Reflux Study in Children grading system (see Table 3).\(^4\) Two common procedures used to assess vesicoureteral reflux are the voiding cystourethrogram (VCUG) and radionuclide cystogram.

Children with known vesicoureteral reflux and a history of UTIs have long had their conditions managed with prophylactic antibiotic medications to prevent UTIs. However, some concern has been raised over the risk of adverse effects from this treatment and the increased risk for antibiotic resistance that can result from the medications’ overuse.\(^4\) In addition, vesicoureteral reflux can resolve

### Table 3

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<th>Grade</th>
<th>Image</th>
<th>Description</th>
<th>Spontaneous Resolution Rate (%)</th>
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<tr>
<td>Grade I</td>
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<td>Reflux into a nondilated distal ureter</td>
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<td>Massive reflux with urethral dilatation and tortuosity and effacement of the calyceal details</td>
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spontaneously by age 10. Most children outgrow reflux, depending on the severity of the disorder.90 Spontaneous resolution is thought to be the result of the normal ureteral growth in length that decreases the likelihood of reflux and occurs in as many as 80% of children with this condition.90

Physicians and researchers have sought the optimal method for treating patients with suspected vesicoureteral reflux resulting in UTIs. Some clinicians believe that vesicoureteral reflux might not play the fundamental role in the pathophysiology of renal damage that was once believed.90 One author suggests instead of imaging for evidence of vesicoureteral reflux, the trend is to more aggressively manage UTIs.90 Accordingly, the American Academy of Pediatrics recently sought to answer several questions regarding testing and management of UTIs in young children (see Box 2).90

According to the 2011 recommendations of the American Academy of Pediatrics, the diagnosis of UTI in a child between 2 months and 2 years of age is based on the presence of both pyuria and at least 50,000 colonies per mL of a single uropathogenic organism.94 Clinical practice guidelines suggest that once the diagnosis is made, the child should undergo appropriate antibiotic treatment for 7 to 14 days with close clinical follow-up.94 The guidelines also suggest ultrasonography of the urinary tract to detect potential anatomical abnormalities such as hydronephrosis. Although a VCUG is not recommended after the first UTI, if a sonogram indicates hydronephrosis or other findings suggestive of obstruction or vesicoureteral reflux, a VCUG is recommended.94 A VCUG also is recommended for recurrent febrile UTIs.94

Although antibiotic prophylaxis remains a core management strategy for UTIs associated with vesicoureteral reflux, surgical intervention is favored for children with higher grades of reflux or apparent renal scarring.95 Vesicoureteral reflux also can be treated with surgical intervention in which the ureter is reimplemented and repositioned or a synthetic bulking agent is injected endoscopically.96

The endoscopic management of vesicoureteral reflux with injection of synthetic or natural materials into the vesicoureteric orifices was introduced into clinical practice more than 25 years ago.96 This procedure is called a subureteral Teflon injection, or STING.96 Materials used in the procedure now include Teflon, silicone, and bovine collagen.96 Dextranomer/hyaluronic acid copolymer (Deflux, Salix Pharmaceutical Inc) is the most recent synthetic material used. The material has been considered successful in most cases, although complications have been reported and include transient infections, transient obstruction, the formation of granulomas, and pseudocysts around the injection site.95 Success rates for STING procedures have been described as lower than those for open surgery.96 Ultrasoundography and fluoroscopy can be used postsurgically to assess the material’s proficiency at preventing reflux and the durability of the synthetic materials used.

**Role of Medical Imaging**

Pediatric patients present unique challenges, including distinctive pediatric pathologies, for health care practitioners. Imaging has become critical for the detection and diagnosis of congenital anomalies and the development of a treatment plan for many pediatric urinary tract conditions.2

**Radiography and Fluoroscopy**

Conventional abdominal radiography can help physicians with general assessment of some urinary tract pathologies, especially those such as renal tumors that distort healthy anatomy. The VCUG, also referred to

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**Box 2**

**American Academy of Pediatrics 2011 Guidelines on Urinary Tract Infections**

In 2011, a committee revising the American Academy of Pediatrics clinical guidelines on diagnosis and management of urinary tract infections (UTIs) in infants and children aged 2 months to 24 months considered the following questions:

1. Which children should have their urine tested?
2. How should the urine sample be obtained?
3. How should UTIs be treated?
4. What imaging and follow-up are recommended after the diagnosis of a UTI?
5. How should children be followed after a UTI has been diagnosed?
as a **micturating cystourethrogram**, is the most frequently performed pediatric fluoroscopic examination in the radiology department for investigating lower urinary tract disease.\(^\text{57}\) The VCUG allows the physician to see the configuration of a child’s urinary bladder and urethra while simultaneously looking for evidence of functional and congenital abnormalities that underlie symptoms (see **Figures 12-13**).\(^\text{47}\)

A child must be catheterized for a VCUG. A 5F to 8F Foley catheter is placed through the urethra to administer iodinated contrast media to the bladder.\(^\text{57}\) Once the bladder is filled, images are obtained of the distended bladder, and then the patient must void on command under direct fluoroscopic imaging while the physician evaluates for evidence of vesicoureteral reflux, dysfunction, congenital anomaly, or other diseases or disorders.\(^\text{57}\) VCUG helps identify the presence of reflux in association with ureteropelvic junction obstruction, ureteroceles, and posterior urethral valves, as well as delineating both bladder and other urethral anomalies.\(^\text{59}\) For the best examination results, the pediatric patient must be cooperative and the fluoroscopic instruments optimized for obtaining rapid images.\(^\text{57}\) Personnel involved in the procedure, including the radiographer or radiologist assistant, radiologist, and parents, must adhere to radiation safety guidelines and work together to promote both patient safety and comfort.

VCUG has been shown to carry a high risk for inducing patient anxiety and distress, which can amplify reluctance to undergo similar procedures in the future.\(^\text{60}\) Several studies have shown that long-term effects of VCUG include behavioral changes, clinging to parents, and disruption in toilet training and sleep.\(^\text{60}\) Preoperative anxiety in young children is associated with additional postoperative complications.\(^\text{60}\) Consequently, researchers have focused on strategies that help reduce the psychological trauma associated with VCUG for pediatric patients.

Some researchers have proposed that sedation is a safe, compassionate, and effective means for preventing emotional stress in most pediatric patients.\(^\text{60}\) Typically, conscious sedation is accomplished using intravenous or injected midazolam or inhaled nitrous oxide.\(^\text{60}\) Conversely, other researchers have proposed that the child’s and parent’s psychological preparation is equally important and possibly just as effective at reducing anxiety. One study found that providing the patient with information before the examination successfully reduced distress compared with children who had no preparation. The study presented the information in the form of a cartoon and storybook with a photograph montage explaining the procedure.\(^\text{61}\) Regardless of the...
CT and MR imaging, and is performed easily at the bedside, which can be invaluable in the diagnosis of pediatric renal disease. Ultrasonography is useful for identifying anatomical variants of the urinary tract, congenital malformation, congenital hydronephrosis, acquired renal obstruction, renal cystic disease, and tumors. It also is helpful for evaluating children for signs of infection and vascular compromise, dilatation of the ureters, abnormalities of the urinary bladder and urethra, and for assessment of renal transplants (see Figure 14).44

Although ultrasonography is useful, it has limitations. For example, ultrasonography is not particularly helpful in evaluating overall renal function, although the use of Doppler flow pattern assessment can provide some beneficial information related to obstructive uropathy and transplant assessment.43 However, a typical urinary tract sonogram has a sensitivity ranging from 11% to 91% and a specificity ranging from 15% to 94% for diagnosing vesicoureteral reflux.44 Ultrasonography cannot rule out vesicoureteral reflux and only detects the condition indirectly.45 It also is operator dependent, especially with pediatric patients. In one study of 864 children, ultrasonography performed following an initial urinary tract infection failed to detect changes associated with vesicoureteral reflux and renal damage.45

Voiding urosonography is similar to the VCUG but without ionizing radiation exposure. Voiding urosonography uses a sonographic contrast agent (SonoVue, Bracco), along with saline, injected into the bladder via catheterization.47,62 Sonographic results typically are not considered dependable; thus, the technique commonly is not used for routine clinical investigation of reflux.44

Nuclear Medicine

Many radiopharmaceutical agents used in nuclear medicine that are detected by scintillation or a gamma camera target specific organs or structures for diagnostic purposes, and others can be used to treat disease. The discharge of ionizing radiation exposes the patient’s vital organs to radiation, and consequently can lead to detrimental health effects.5

For pediatric urology patients, nuclear medicine is useful for evaluating renal function in 3 regards: excretion by glomerular filtration, excretion by tubular secretion,
and renal cortical assessment.\textsuperscript{63} Technetium Tc 99m dimercaptosuccinic acid (DMSA) is the most common radiopharmaceutical used for evaluating the renal cortex for signs of scarring and masses.\textsuperscript{63} Tc 99m DMSA is administered to the patient intravenously, and imaging typically is performed after a 2- to 3-hour delay to allow the radiopharmaceutical to be absorbed by the cortex.\textsuperscript{50} Tc 99m DMSA is the agent of choice for diagnosing congenital dysplasia and acute pyelonephritis.\textsuperscript{37,64}

The combination of renal scintigraphy with Tc 99m DMSA along with urinary tract ultrasonography yields a negative predictive value of 92%.\textsuperscript{64} A limitation of Tc 99m DMSA scintigraphy is that the images cannot help distinguish between long-term scarring and lesions that will spontaneously resolve. As a result, the examination is not recommended for evaluating pediatric patients for vesicoureteral reflux because of a high percentage of false-negative studies.\textsuperscript{37,64} Renal scar delineation with scintigraphy cannot be seen for up to 6 months following a case of acute pyelonephritis as well.\textsuperscript{7} Although Tc 99m DMSA can be effective, the radiation dose for the examination is high, at approximately 1 mSv.\textsuperscript{43}

The radionuclide cystogram is a nuclear medicine examination used to diagnose vesicoureteral reflux and is considered more sensitive than VCUG.\textsuperscript{64} A radionuclide cystogram also can help detect sporadic reflux, which might be missed with intermittent fluoroscopy.\textsuperscript{64} In addition, the radionuclide cystogram exposes children to less radiation than does a VCUG.\textsuperscript{64} A potential drawback of the radionuclide cystogram compared with VCUG is poorer spatial resolution. The physician cannot readily identify bladder and urethral morphology because of poor spatial resolution, and an alternate examination might be required. Thus, the nuclear medicine examination often is seen as a less cost-effective procedure.\textsuperscript{51,64} The use of the bladder volume-graded direct radionuclide cystogram appears to be highly sensitive and specific for assessing bladder function and detecting reflux at various bladder volumes during filling and voiding phases.\textsuperscript{51}

**Conclusion**

Medical diagnostic imaging is invaluable in the diagnosis and treatment of various urinary tract conditions. Pediatric patients have special needs, and it is incumbent upon imaging professionals to strive to learn more about the unique diseases of the pediatric patient and to offer each patient optimal care.

Steven M Penny, MA, R.T.(R), RDMS, is lead instructor of the medical sonography program for Johnston Community College in Smithfield, North Carolina. Mr Penny specializes in abdominal, obstetric and gynecological, and pediatric sonography.

Reprint requests may be mailed to the American Society of Radiologic Technologists, Communications Department, at 15000 Central Ave SE, Albuquerque, NM 87123-3909, or emailed to communications@asrt.org.

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**References**


Read the preceding Directed Reading and choose the answer that is most correct based on the article.

1. The kidneys filter the body's entire blood volume approximately every ______ minutes.
   a. 2
   b. 10
   c. 40
   d. 90

2. The site at which the ureter meets the bladder is called the ______ junction.
   a. ureterovesical
   b. ureteropelvic
   c. ureterourethral
   d. trigonalvesicular

3. The metanephric kidneys initially develop within the:
   a. fetal chest.
   b. fetal pelvis.
   c. base of the umbilical cord.
   d. cloaca.

4. ______ is likely caused by a urinary tract obstruction during fetal development.
   a. Autosomal dominant polycystic kidney disease
   b. Medullary nephrocalcinosis
   c. Autosomal recessive polycystic kidney disease
   d. Multicystic dysplastic kidney disease

5. Which is the most common congenital anomaly of the urinary tract?
   a. vesicoureteral reflux
   b. duplication of the renal collecting system
   c. horseshoe kidney
   d. ureteropelvic junction obstruction

6. Which is the most common cause of bladder outlet obstruction in newborn boys?
   a. vesicoureteral reflux
   b. horseshoe kidney
   c. posterior urethral valves
   d. Beckwith-Wiedemann syndrome

continued on next page
Directed Reading Quiz

7. Which of the following renal tumors is the most common renal malignancy in children?
   a. nephroblastoma (Wilms tumor)
   b. neuroblastoma
   c. angiomyolipoma
   d. hemangioma

8. Which is the most common abdominal malignancy in newborns?
   a. Wilms tumor
   b. angiomyolipoma
   c. neuroblastoma
   d. tuberous sclerosis

9. Which bacteria is implicated in nearly 80% of urinary tract infections (UTIs)?
   a. Enterococcus
   b. Klebsiella
   c. Streptococcus
   d. Escherichia coli

10. Scarring of the renal parenchyma from conditions, such as congenital dysplasia, ultimately can lead to:
    1. adult hypertension.
    2. end-stage renal disease.
    3. toxemia during pregnancy.
    a. 1 and 2
    b. 1 and 3
    c. 2 and 3
    d. 1, 2, and 3

11. To prevent UTIs, children with known vesicoureteral reflux disease and a history of UTIs have been managed mostly with:
    a. renal transplant.
    b. prophylactic antibiotic medications.
    c. surgical resection.
    d. behavioral modification therapy.

12. A voiding cystourethrogram is the most frequently performed fluoroscopic examination in the pediatric radiology department for investigating lower urinary tract disease.
   a. true
   b. false

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