IMAGING IN PEDIATRIC UROLOGY

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The pediatric genitourinary tract may be affected by many disorders, most of which are congenital and some acquired. Patients presenting with signs and symptoms related to the genitourinary tract often need imaging for diagnosis and management. In this article, a problem-oriented approach is used to discuss the following clinical urologic problems: (1) urinary tract infection (UTI), (2) hydronephrosis or hydroureter, (3) genitourinary trauma, (4) swollen scrotum, and (5) hematuria.

THE CHILD WITH URINARY TRACT INFECTION

UTI is one of the most frequently encountered clinical problems in children. Despite the common occurrence of UTI, the diagnostic work-up and management remain a constant challenge for pediatricians. There are many approaches to evaluating children with UTIs; however, the ultimate goal of the diagnostic work-up is to identify kidneys at risk for acute pyelonephritis (AP) and subsequent renal scarring. The task may become simpler by addressing two important questions: Is the infection limited to the bladder, or does it involve the kidney resulting in acute

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pyelonephritis; and are there underlying anatomic abnormalities in the urinary tract that predispose to infection, most importantly vesicoureteral reflux (VUR) and obstruction.

Diagnosis and Imaging of Acute Pyelonephritis

The importance of making the distinction between AP and lower UTI lies in the fact that AP can lead to irreversible parenchymal damage that may result in the development of hypertension, renal insufficiency, or both. It has been shown that delay in treatment is a major factor for the development of renal scarring.[41] The clinical signs and symptoms of AP in infants and young children are often nonspecific and indistinguishable from those of lower UTI. Therefore, imaging is often necessary to differentiate between AP and lower UTI.

At the present time, renal cortical scintigraphy (RCS) utilizing ^{99m}technetium (^{99m}Tc)-dimercaptosuccinic acid (DMSA) or glucoheptonate has been shown to be the most practical and reliable method for the detection of AP. In an experimentally induced pyelonephritis study done in piglets, the sensitivity for the diagnosis of AP using DMSA was 87% and specificity 100% using strict histopathologic criteria as the standard of reference.[30] After intravenous injection, ^{99m}Tc-DMSA is taken up by the tubular cells in the cortex. Uptake of DMSA is dependent on blood flow and intact tubular cell function. AP causes local ischemia and tubular dysfunction; thus involved areas have decreased uptake of the DMSA.[19] On high resolution pinhole images of the kidney, AP
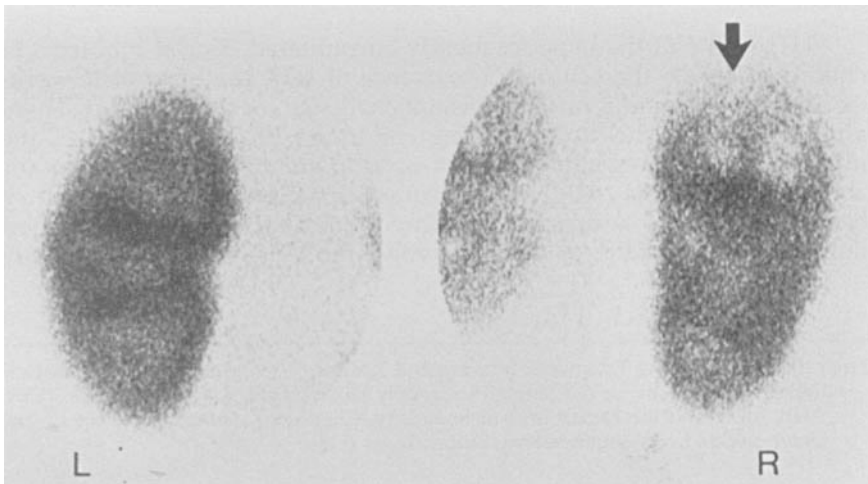

Figure 1. Acute pyelonephritis in a 5-month-old girl with febrile urinary tract infection. DMSA renal scan shows decreased tracer uptake without volume loss, upper pole right kidney (arrow).
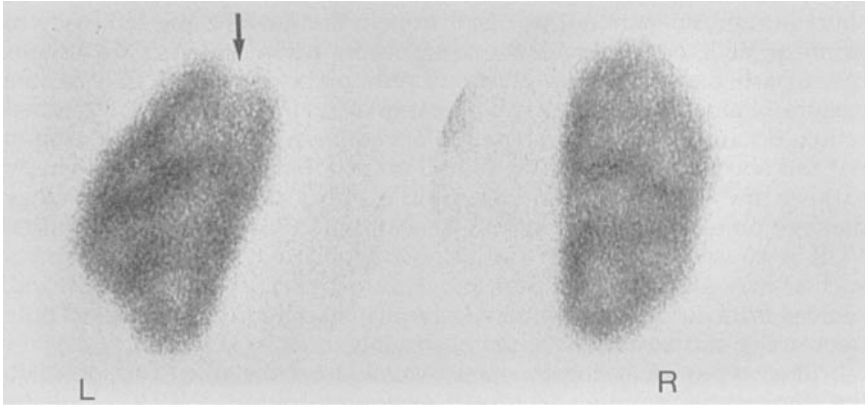
Figure 2. Renal scar in a 3-year-old girl with previous pyelonephritis. DMSA renal scan shows focal decreased uptake with volume loss, upper pole left kidney *(arrow).*

appears as focal, multifocal, or diffuse areas of decreased tracer uptake in the kidney without volume loss (Fig. 1). Calculation of differential renal function also can be obtained. Scarring is also well seen on DMSA scan as areas of decreased uptake associated with volume loss (Fig. 2).

Other imaging modalities have been used to diagnose AP. Conventional gray-scale sonography has been done but has a low sensitivity for the detection of AP. Recent research with power Doppler sonography shows promise.[8] Contrast-enhanced computed tomography (CT) has been used to diagnose AP, depicted as areas of low attenuation in the kidney. The perinephric space is also well delineated on CT, and renal function can be assessed; however, iodinated contrast is required for CT studies, which carries with it the risk of allergic reaction. CT also has a role in the evaluation of a suspected renal or perinephric abscess in a child being treated for AP who is not responding to seemingly appropriate antibiotic therapy. Sonography may also be used to evaluate for renal or perinephric abscess; however, CT is the study of choice in this clinical situation because of more precise delineation of the retroperitoneum. The role of magnetic resonance (MR) imaging in the diagnosis of AP has yet to be elucidated.[27]

Imaging of Anatomic Abnormalities of the Urinary Tract

Radiologic investigation of the urinary tract for congenital anatomic abnormalities is required to answer the second question. Vesicoureteral reflux (VUR) is the most common abnormality, occurring with a prevalence of 35% in children with UTI.[37] Reflux provides a ready-made pathway for bacteria to ascend to the kidney and cause infection. Primary VUR, the most common type of reflux, is caused by an abnormally

short intramural segment of distal ureter. Fortunately, the tendency of primary VUR is for spontaneous resolution, which occurs in 85% of cases, particularly in lower grades of reflux. This is the rationale for the current standard of nonsurgical treatment of patients with diagnosed reflux. Because it is the combination of reflux and infection that leads to AP and scarring, the patient is placed on prophylactic antibiotic therapy to keep the urine infection free. Sterile reflux does not cause kidney damage unless it is associated with obstruction. Secondary or acquired VUR is caused by bladder outlet obstruction that may be functional, such as in neuropathic bladders and dysfunctional voiding, or structural, such as from a posterior urethral valve. This kind of reflux resolves only upon relief and treatment of the obstruction.

Two types of cystograms are available for the diagnosis of VUR, the fluoroscopic voiding (contrast) cystourethrogram (VCUG) and the radionuclide (isotope) cystogram (RNC). The VCUG has excellent anatomic resolution and provides high detail images of the bladder and urethra. Imaging of the urethra is essential in boys to exclude posterior urethral valve. Bladder wall abnormalities, such as trabeculation, diverticula, and ureteroceles are well seen. The VCUG also provides accurate grading of reflux using the International Classification of I through V.[13]

Radionuclide cystography is extremely sensitive for the detection of reflux. This is because of the continuous monitoring during the entire examination, from the beginning of filling to after voiding. The radionuclide cystogram has lower spatial resolution than the VCUG; thus bladder wall abnormalities mentioned above may go undetected. In addition, the urethra cannot be evaluated; however, the RNC has the distinct advantage of a much lower radiation burden to the patient, as much as 20 to 50 times less compared with the fluoroscopic VCUG. VUR is graded on RNC as mild, moderate, and severe. The choice of cystogram may vary depending on the clinical situation, physician preference, and the experience of the radiologist. The following guidelines should be considered. The VCUG should be used in boys for the first-time work-up of UTI to allow evaluation of the urethra. Also, patients with history of dysfunctional voiding should be evaluated by the VCUG to evaluate the bladder wall. The RNC should be used for postoperative follow-up after surgical correction, follow-up in all patients with known reflux, and for screening asymptomatic siblings of patients with reflux (boy or girl). The occurrence of VUR in siblings of patients who reflux may be as high as 45%.[39] RNC also may be used in the initial evaluation of girls with UTI because urethral anomalies are rare, and significant bladder wall abnormalities are detected on sonography.

The timing of performing the cystogram is an issue that has met with varying opinions and practices. The cystogram should be performed after antibiotic therapy has begun; however, it is not necessary to wait a prolonged period after treatment. The notion that imaging during the infection may cause a false-positive result of reflux should be dispelled. Reflux at any time is abnormal, and reflux occurring during an infection is perhaps the most significant in that it is during this time

that renal infection and subsequent damage may occur; however, in patients with dysuria or other symptoms of cystitis, it may be prudent to wait until these symptoms subside so that adequate bladder filling can be obtained during the cystogram. Underfilling of the bladder may result in a false-negative result for VUR.

Acute Pyelonephritis, Vesicoureteral Reflux, and Renal Scarring

The relationship between acute pyelonephritis, vesicoureteral reflux, and renal scarring is becoming clearer with recent studies using cortical scintigraphy. Up until recent years, the search for acute pyelonephritis was limited to patients with diagnosed VUR; however, in a recent study, Majd and colleagues[20] showed that VUR was present in only 37% of patients with DMSA scan evidence of AP. Therefore, limiting the investigation for AP to only those children who have reflux would result in most cases of AP being missed. Scar formation in patients with acute pyelonephritis was assessed in the data of Rushton and colleagues.[31] The prevalence of scar formation following AP was approximately 43%, regardless of the presence or absence of reflux.[31] Furthermore, scars formed only at the sites of acute pyelonephritis. Therefore, in children with febrile UTI or in whom AP is a possibility, cortical scintigraphy should be considered to evaluate for AP even if there is no demonstrable reflux on the cystogram.

Hydronephrosis or Hydroureter

Sonography is the most sensitive imaging modality for the detection of hydronephrosis and hydroureter. Hydronephrosis and hydroureter are fully discussed in the next section.

Recommendations for Imaging

It is the current standard of practice that children (girls and boys), undergo diagnostic imaging evaluation after the first documented UTI. The selection and order of performance of the imaging studies for children with UTIs depends on the age, sex, and degree of illness of the patient. The basic principle is that a reflux study and kidney imaging are needed. Children who are admitted to the hospital because of fever and toxicity associated with their UTIs should have a sonogram early in the course to rule out pyonephrosis, which may need immediate nephrostomy. A DMSA scan should then be performed to help make the diagnosis of AP, particularly in infants and toddlers. After treatment and just before discharge, a cystogram should then be performed to evaluate for VUR. In patients with afebrile UTI, the cystogram should

be performed first. Patients with reflux should undergo DMSA renal scan to evaluate for scarring. If there is no reflux, a sonogram may be performed to evaluate the kidneys. Afebrile children with reflux and DMSA scans may not need sonograms if the DMSA scan is performed in a nuclear medicine department with experience in cortical scintigraphy, where significant hydronephrosis and complicated duplications would be easily recognized.

CHILDREN WITH HYDRONEPHROSIS OR HYDROURETER

Dilatation of the collecting system may involve any or all portions of the collecting system from the renal calyces to the ureterovesical junction, resulting in various degrees of hydronephrosis or hydroureter. Hydronephrosis/hydroureter (H/H) may present with UTI, abdominal pain, abdominal mass, renal failure, or hypertension or may be found incidentally during abdominal imaging for other indications. In recent years, however, the diagnosis of H/H is being made with greater frequency and much earlier, before the appearance of symptoms, because of the widespread use of prenatal sonography. Hydronephrosis is the most commonly detected prenatal sonographic abnormality.[21] Sonography is extremely sensitive, both in children and in the fetus, for the detection of H/H. In the case of prenatally diagnosed H/H, a postnatal sonogram should be obtained to confirm the presence of H/H, but not earlier than 1 week of age. Before this age, studies are less reliable because of a normal period of physiologic dehydration in the first week to 10 days of life.[5] If the postnatal renal sonogram is normal, the rest of the abdomen should be sonographically examined to rule out a nonrenal mass simulating hydronephrosis. Alternatively, the possibility of an intermittent cause of hydronephrosis, such as vesicoureteral reflux, should be considered. Vesicoureteral reflux is identified in as many as 40% of prenatally diagnosed hydronephrosis, with half of these cases being bilateral.[43] Whether H/H is detected prenatally or postnatally it is essential to assess for the presence of VUR, evaluate renal function, and determine if the H/H is obstructive or nonobstructive. Causes of H/H in children include nonobstructive causes, such as vesicoureteral reflux, nonobstructed primary megaureter, and prune-belly syndrome; and obstructive disorders including ureteropelvic junction (UPJ) and ureterovesical junction (UVJ) obstruction, posterior urethral valve, and complicated duplicated collecting systems.

Vesicoureteral Reflux

The initial imaging work-up for H/H should begin with a cystogram, radiographic or nuclear, to exclude the presence of reflux. VUR causing H/H is usually of a high grade (grade IV/V, or severe). If the

refluxing system adequately drains on the cystogram, one can reasonably exclude coexistent obstruction; however, a renal scan to evaluate the function of the refluxing system is necessary. If drainage of the refluxing system is not seen on the cystogram, then the possibility of a coexistent obstruction is present and further imaging is necessary.

Obstruction Versus Nonobstruction

Diuretic renography (DR) is the imaging modality used to differentiate obstructive from nonobstructive H/H.[18] DR is performed using ^{99m}Tc-DTPA or ^{99m}Tc-MAG3. Oral hydration is encouraged, and an intravenous line is placed for hydration. A bladder catheter is inserted and remains in place for the length of the study. Bladder decompression is essential for several reasons: to eliminate the effect of a full bladder on upper collecting system drainage, to prevent reflux (if present), and to minimize gonadal radiation exposure from the radioactive urine. After injection of DTPA/MAG3, sequential images of the kidney are obtained. Following excretion and maximal filling of the dilated collecting system or ureter with radioactive tracer, furosemide is injected intravenously (1 mg/kg), and imaging continues. Differential renal function is calculated. The drainage pattern of each kidney is interpreted using the images and washout half-times calculated from computer-generated furosemide washout curves. Management of H/H is based on results of the diuretic renogram, patient age, and renal function.

Ureteropelvic Junction Obstruction

UPJ obstruction is the most common congenital renal abnormality. Currently, most cases of UPJ obstruction in infants are detected by prenatal sonography. In older children, presentation may be UTI, intermittent abdominal pain, or hematuria following minor trauma. Occasionally, UPJ obstruction may be acquired because of calculus or blood clot. The sonographic diagnosis of UPJ obstruction is strongly suggested by moderate to severe dilatation of the renal pelvis and calyces without ureteral dilatation. DR demonstrates minimal or no drainage from the dilated collecting system (Fig. 3). Renal function of the affected kidney is often preserved in neonates with UPJ obstruction. A cystogram also should be performed to rule out coexistent reflux. Management depends on age and the affected kidney's function. It has been shown that young infants with indeterminate or even definite obstruction on DR and preserved renal function do not need immediate pyeloplasty.[12] Rather, they may be placed on antibiotics and a follow-up DR obtained in 3 months' time to assess for any change in drainage pattern or deterioration in the function of the affected kidney. Improvement and even normalization of drainage can occur over time in this group of patients, possibly related to an initial functional rather than mechanical obstruc-
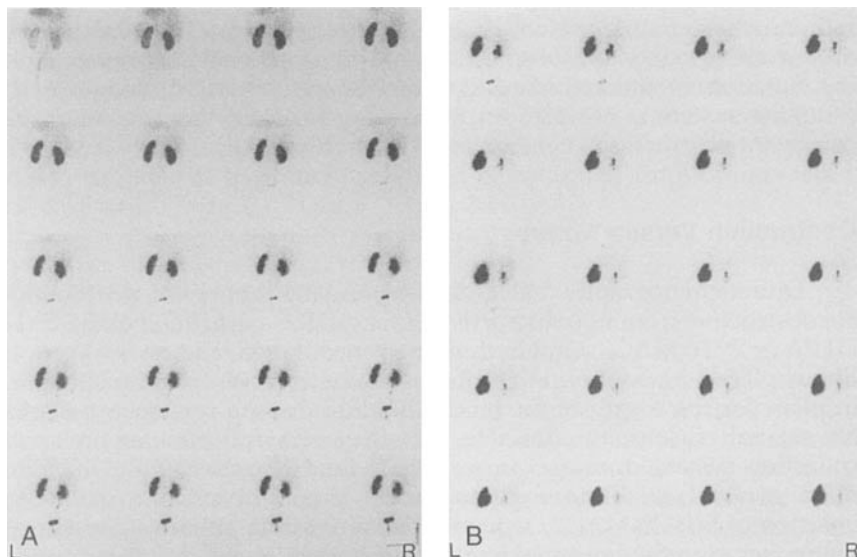
Figure 3. Ureteropelvic junction obstruction on MAG3 diuretic renogram in a 2-week-old male infant with prenatal diagnosis of left hydronephrosis. *A,* Initial images show prompt bilateral excretion, dilated left collecting system, and normal drainage from right collecting system. *B,* After furosemide, right collecting system drains completely and dilated left collecting system shows no drainage.

tion. Older symptomatic children diagnosed with UPJ obstruction and children of any age with obstruction and compromise of that kidney's function will need surgical intervention.

Ureterovesical Junction Obstruction

UVJ obstruction may be caused by congenital primary megaureter, an entity in which the distal-most ureteral segment is adynamic, preventing normal propagation of urine.[29] Other causes include congenital stenosis of the distal ureter, calculi, blood clots, or obstruction from a pelvic mass. Dilatation is often limited to the ureter; however, it may involve the collecting system to varying degrees. DR demonstrates obstruction at the distal ureter. A cystogram should also be obtained to exclude reflux. Management is similar to that for UPJ obstruction.

Complicated Duplications—Ectopic Ureterocele and Ectopic Ureteral Insertion

Complete duplication of the collecting system is a term referring to congenital division of the renal pelvis into two moieties, usually upper and lower, each drained by its own ureter. The ureters then enter the

bladder separately at two different orifices. Most duplicated collecting systems are uncomplicated and are not associated with symptoms or an increased risk for infection; however, some have VUR, usually into the lower pole moiety or obstruction of the upper pole moiety ureter by either an ectopic ureterocele or ectopic ureteral insertion. With both entities, there is often dysplasia and hydronephrosis and hydroureter of the upper pole moiety. Complicated duplications are usually diagnosed or suspected on prenatal sonography.[25] In patients who are diagnosed postnatally, UTI is a common presentation. Constant wetness or urine leakage may be a feature with ectopic ureteral insertion in girls only because the ureter may insert anywhere along the lower genitourinary tract, including the vagina or perineum. In boys, the ectopic ureter always terminates above the external sphincter; thus, urine leakage is not present. The ectopic ureterocele is an abnormal ballooning of the upper pole moiety distal ureter that inserts ectopically into the bladder. The ureterocele at times may also obstruct the ipsilateral lower pole moiety ureter distally, causing dilatation of the lower pole moiety collecting system and ureter. With ectopic ureterocele and ectopic ureteral insertion, the lower pole tends to have VUR, and a VCUG should be performed, which can also demonstrate the ureterocele (Fig. 4). A renal
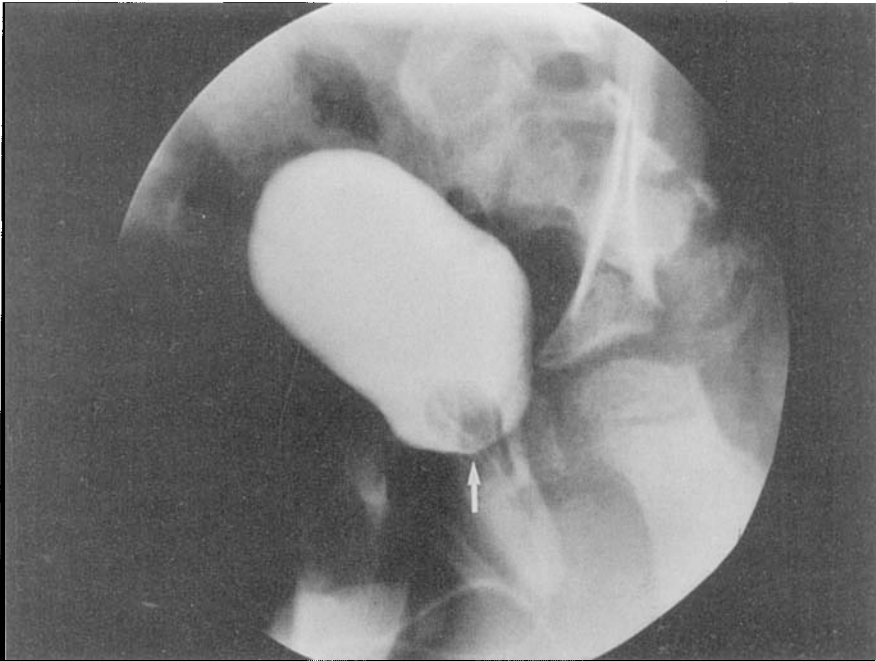

Figure 4. Ectopic ureterocele in a 2-year-old female presenting with urinary tract infection. Voiding cystourethrogram demonstrating low-lying filling defect *(arrow)* in contrast-filled bladder.

scan should also be obtained to assess the function of the duplicated kidney. The amount of contribution of the affected upper pole moiety to total renal function determines how the patient will be managed.

Posterior Urethral Valve

Posterior urethral valve (PUV) is an important entity causing obstruction in the urinary tract in boys.[33] PUV causes near-complete obstruction to urine outflow. Subsequent bladder wall thickening and hypertrophy are present, which often result in secondary VUR and UVJ obstruction. This chronic obstruction in utero often results in dysplasia of the kidneys and varying degrees of renal insufficiency at birth. The diagnosis is often made in utero by sonography, with findings of bilateral hydronephrosis and hydroureter associated with an enlarged thick-walled bladder. The kidneys may have dysplastic changes with increased echogenicity and cortical cysts. Patients not diagnosed prenatally often present with a UTI. A VCUG is necessary to demonstrate the valve and the dilated posterior urethra (Fig. 5) and reflux. DR should be obtained to assess renal function and exclude the presence of associated
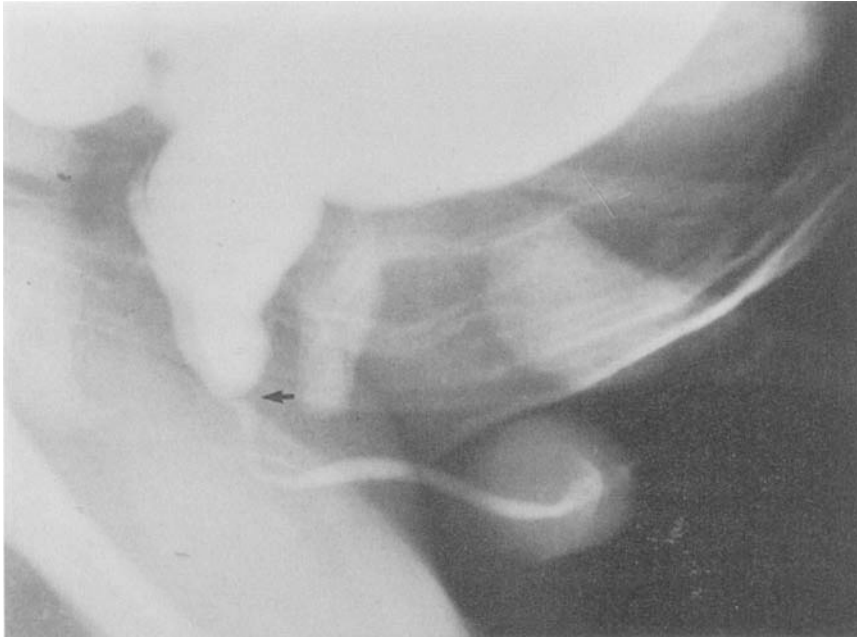

Figure 5. Posterior urethral valve in a 1-day-old infant male with prenatal sonogram demonstrating bilateral hydronephrosis/hydroureter. Voiding cystourethrogram shows filling defect at level of the posterior urethral valve *(arrow)* with proximal dilatation of posterior urethra.

UVJ obstruction that does not improve after decompression of the obstructed bladder.

CHILDREN WITH GENITOURINARY TRAUMA

Injury to the genitourinary tract in children occurs most commonly from blunt abdominal trauma and less commonly from penetrating injuries. Blunt abdominal trauma is usually secondary to motor vehicle accidents and falls. With penetrating trauma, patients usually proceed to direct surgical exploration; however in patients with blunt abdominal trauma, imaging is often needed to delineate visceral injuries. The genitourinary tract is involved in 10% of patients with blunt abdominal trauma.[22] Injuries can involve the kidney, adrenal gland, bladder, urethra, and scrotum. Injury to the genitourinary tract is often suspected when hematuria, gross or microscopic, is present. In addition, the presence of pelvic fracture with the hematuria strongly suggests a lower urinary tract injury. There are often associated injuries with other viscera in patients with genitourinary trauma.

Kidney

Renal injuries occur in 5% to 12% of children with blunt abdominal trauma.[1, 36] Kidneys with underlying congenital abnormalities, such as ureteropelvic junction obstruction, or kidneys in an ectopic location, such as pelvic kidney, are at higher risk for injury. The kidney is the most common organ affected when considering genitourinary tract injuries. Although most patients with renal injury have hematuria, the degree of hematuria does not correlate with severity of renal injury.[36] Occasionally, vascular pedicle injury occurs without hematuria. Other signs that suggest renal injury are flank pain and tenderness, ecchymosis, and the presence of other visceral injury.

Contrast-enhanced computed tomography (CT) is the best available imaging technique to diagnose and characterize renal injuries. It is quick and noninvasive, and provides information regarding renal function. It also allows simultaneous evaluation for other intra-abdominal injuries. Several systems for grading renal injuries on CT have been used. Yale-Loehr suggested the following classification[42]: grade I includes small parenchymal hematoma and contusion; grade 2 is parenchymal laceration limited to the cortex; grade 3 is parenchymal laceration extending to the collecting system; and grade 4 is vascular pedicle injury, complete (avulsion) or segmental. Lacerations often result in perirenal hematomas and, in the case of collecting system involvement, urinomas. It may be difficult to distinguish hematoma from urinoma around the kidney on initial CT scan. Fifteen- to 20-minute delayed CT images may be obtained to see if contrast-opacified urine enters the collection, thus indicat-

ing a urinoma (Fig. 6). Alternatively, a follow-up abdominal radiograph may be taken portably if the patient cannot wait for delayed CT images.

The current treatment of most renal injuries is observation, except in cases of renal pedicle avulsion or hemodynamic instability, both of which necessitate immediate surgery. Patients with lacerations, with or without perirenal hematoma or urinoma may also initially be managed nonoperatively.[3, 14] Early follow-up imaging in patients with perinephric collections is usually needed during the hospital stay and can be done using sonography to assess change in size of the collection. Alternatively, a nuclear renal scan using ^{99m}Tc-glucoheptonate can be obtained. Glucoheptonate is a renal agent that is 80% excreted and 20% bound in the renal cortex. Thus, ongoing urine leak can be detected. In addition, information regarding renal function and focal parenchymal loss can be obtained.

Further imaging follow-up 3 to 4 months after the injury may be limited to patients with grades 3 and 4 injuries in whom loss of renal function, hypertension, and hydronephrosis may occur.[1] Follow-up evaluation may be performed with CT or glucoheptonate scan.

Adrenal

The adrenal glands are infrequently injured in patients with blunt abdominal trauma. In a large series of patients with blunt abdominal trauma imaged with CT, Sivit and colleagues[35] found adrenal hematomas in only 3% of patients. Ipsilateral abdominal and thoracic injuries frequently were present. Resolution of hematoma usually occurs over a few months' time and may be followed by CT or sonography. In this series of patients, no long-term complications, particularly adrenal insufficiency, developed.

Bladder

Bladder rupture occurs most often because of blunt trauma to the abdomen. When present, nearly 90% of bladder injuries are associated with pelvic fracture; however, only 10% of all patients with pelvic fractures have lower urinary tract injury.[32] Blood may be present at the urethral meatus, in which case urethral injury should be excluded first.

Two patterns of bladder rupture are seen, the more common of which is extraperitoneal, and the less common, intraperitoneal. Intraperitoneal rupture usually occurs secondary to blunt trauma to a distended bladder. The perforation occurs at the dome posteriorly, the only portion of the bladder covered by peritoneum. Abdominal pain and tenderness are usually present. Extraperitoneal rupture usually occurs low at the bladder neck and is more strongly associated with pelvic fracture than intraperitoneal rupture.

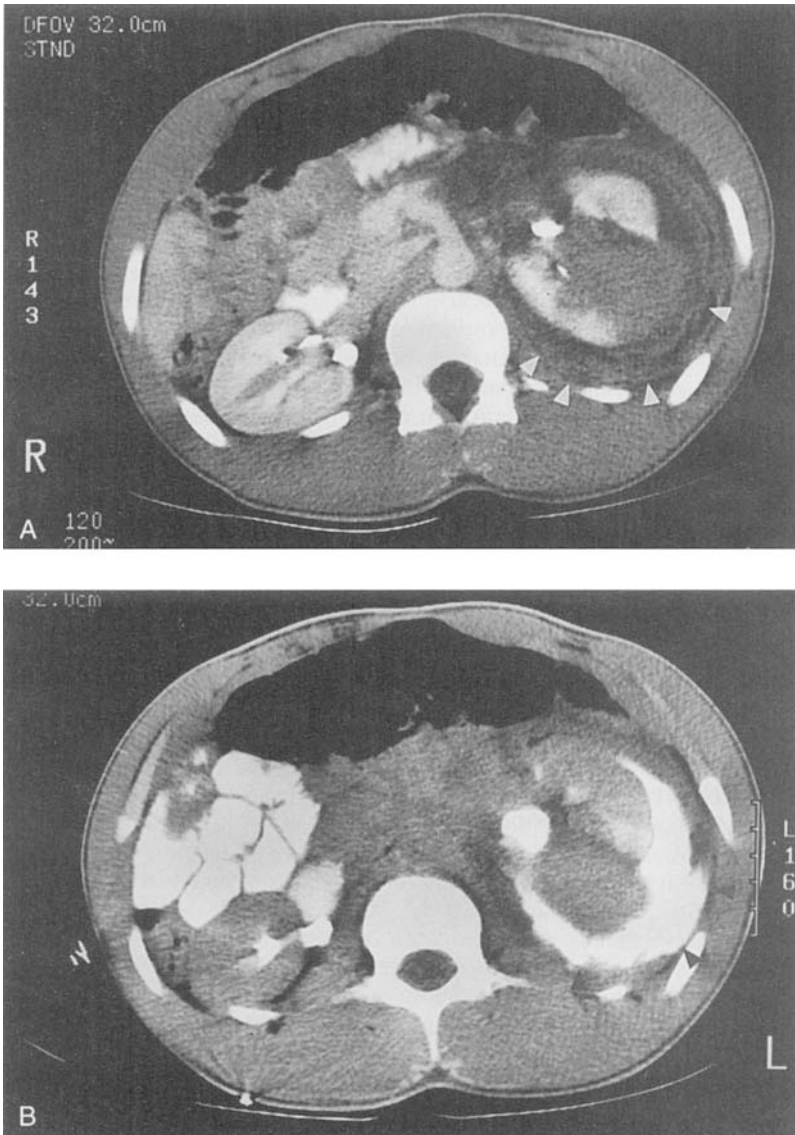The imaging diagnosis of bladder rupture, intraperitoneal or extra-

Figure 6. Renal laceration with perinephric urinoma in a 14-year-old boy in a motor vehicle accident. *A,* Contrast-enhanced CT scan demonstrates grade 3 renal injury of left kidney with perinephric fluid collection *(arrowheads). B,* Delayed scan shows filling of perinephric space by contrast-opacified urine indicating a urinoma *(arrowheads).*

peritoneal, may be performed by retrograde cystography, CT, or both (CT cystography). The choice depends on the experience and practice of the radiology department and also whether the patient is undergoing CT anyway for evaluation of other injuries. Retrograde cystography, using iodinated contrast, may be performed if the patient is not being evaluated with CT. With CT, imaging of the upper abdomen is done after usual injection of contrast. The Foley catheter is then clamped, and after a 5-minute delay to allow bladder filling, the bladder is scanned.[34] If no extravasation is seen, further delayed CT imaging (10 minutes later) can be performed. With CT cystography technique, before the administration of intravenous contrast, diluted contrast is instilled into the bladder via Foley catheter, and the abdomen and pelvis are scanned. Subsequently, the usual CT scanning through the abdomen and pelvis is performed.[16] CT with delayed imaging has been shown to be adequate for detection of bladder injuries[34]; however if no extravasation is seen, and clinical suspicion for bladder injury is still high, then CT cystography may be performed. Intraperitoneal rupture is seen on CT, and CT cystography as extravasated contrast in spaces around bowel and paracolic gutters. Extraperitoneal rupture is delineated by streaky contrast in the perivesical space anteriorly and laterally and the retrorectal presacral space. CT and CT cystography have several advantages over retrograde cystography. The patient does not have to be moved from the supine position used for CT scanning, whereas multiple positions are needed for retrograde cystography. This can be difficult in patients with pelvic fractures. CT scanning permits evaluation of all walls of the bladder at every level and is more sensitive for detection of small amounts of extravasated contrast.

The distinction between intraperitoneal and extraperitoneal rupture is important in that the management of each is completely different. Extraperitoneal bladder rupture is usually managed conservatively with catheter drainage and follow-up examination in 10 days to check for persistent leak. Intraperitoneal bladder rupture is treated with immediate surgical exploration and repair of the bladder tear.

Urethra

Urethral injuries are almost exclusively limited to boys. They are less common than bladder injuries, but the two may coexist. The posterior urethra is the segment usually involved with blunt abdominal trauma and pelvic fracture. Anterior urethral injuries are usually caused by straddle-type falls and injuries.[24] As with bladder injuries, hematuria, especially gross, in the presence of pelvic fracture is strongly suggestive of a urethral injury. Blood may be present at the urethral meatus or on spontaneously voided urine. Occasionally, patients may not be able to void.

When urethral injury is suspected, a retrograde urethrogram is performed before attempted placement of a Foley catheter into the blad-

der. Retrograde urethrography is performed by placing the tip of a Foley catheter in the urethral meatus without inflation of the balloon. Contrast is then gently injected into the catheter under fluoroscopy, and images are obtained in an oblique position. If the urethra is normal and contrast enters the bladder, the Foley catheter may be safely advanced into the bladder and the balloon inflated to secure the catheter. Extravasation of contrast into the periurethral tissue indicates a urethral tear. With a partial tear, some contrast enters the bladder. With a complete tear, no contrast enters the bladder. With either complete or partial urethral disruption, a suprapubic tube is placed into the bladder. Treatment is usually conservative, allowing the acute traumatic inflammatory changes to subside. Surgical reconstruction is then undertaken. Long-term complications include stricture and impotence.

CHILDREN WITH SWOLLEN SCROTUM

The acute painful scrotum is an emergent condition because 30% of cases are caused by testicular torsion.[7] The remaining 70% are caused by nonsurgical conditions, such as epididymitis and/or orchitis, torsion of the appendix testis, and trauma.[7, 11] The rate of testicular salvage with testicular torsion is the highest with 6 hours or less of symptoms.[11, 15] In children in whom the duration of symptoms is short and in whom clinical history and physical examination strongly suggest the diagnosis of acute testicular torsion, imaging studies may be bypassed in favor of surgical exploration.[15] Imaging studies can assist urologists because clinically it may be difficult to distinguish between surgical and nonsurgical disease.[11]

Radiologic assessment of the pediatric scrotum has undergone a transition within the past five years. Previously, nuclear scintigraphy was the primary imaging modality used to evaluate the acutely painful and swollen scrotum.[23] With the advent of color and power Doppler blood flow imaging, sonography has assumed a new role in the assessment of the painful scrotum.[2, 11, 17, 26] At many institutions, including the authors', sonography is frequently the first study performed; however, a skilled sonographer is needed together with an awareness of certain sonographic pitfalls. Scintigraphy is still necessary in certain situations, especially in the diagnosis of acute testicular torsion in prepubertal children or for confirmation of sonographic findings if the diagnosis is equivocal. At the authors' hospital, they find that scintigraphy and sonography have a complementary role in difficult cases. Assessment of the enlarged, but nonpainful, scrotum is best accomplished with sonography.

Imaging Technique

Technique is of utmost importance in the performance of testicular sonography. A high-frequency linear transducer (7.5 MHz) should be

used and Doppler settings optimized for the detection of slow flow.[17] Each study should begin with an assessment of the asymptomatic hemiscrotum to obtain a baseline for comparison with the symptomatic side. In the prepubertal testis, normal intratesticular flow is seen as dots and dashes, or only the capsular branch of the testicular artery may be seen. Obtaining an arterial pulsed Doppler tracing helps confirm if true blood flow has been detected rather than noise.[26] Power Doppler may further assist in the detection of intratesticular blood flow.[7] In the postpubertal testis, intratesticular flow is more readily apparent as elongated vessels (centripetal and recurrent rami branches of the testicular artery) but also may appear pulsatile. The normal epididymis is triangular in shape and has no or minimal detectable blood flow.[17]

Testicular scintigraphy is performed with intravenous injection of ^{99m}Tc-pertechnetate and includes a blood flow study and static images.[23] The normal examination shows symmetric blood flow in both testes.

Testicular Torsion

Testicular torsion occurs most frequently in infants and adolescents.[23] Sonographic and scintigraphic findings in testicular torsion are dependent on duration of symptoms. In early-phase torsion (less than 24 hours of symptoms), color Doppler sonography and scintigraphy show absent or decreased intratesticular blood flow (Fig. 7). In addition, on sonography, the epididymis can be markedly enlarged because of venous obstruction with vascular engorgement and also show no flow.[17] In late torsion (greater than 24 hours of symptoms), color Doppler sonography and scintigraphy demonstrate the "doughnut sign" with absent intratesticular blood flow and a markedly hyperemic rim caused by increased flow in the surrounding scrotal tissues (Fig. 8).

Testicular torsion may be seen in neonates and usually is a prenatal event[4]; however, postnatal torsion does occur in the first month of life.[9] A typical sonographic appearance is an enlarged, avascular testis sometimes with a thin hyperechoic rim caused by calcification from ischemic necrosis. The testis may contain hypoechoic areas or may be heterogeneous in texture.

Pitfalls may occur in the imaging diagnosis of acute testicular torsion. On sonography, there may be little or no intratesticular blood flow detected in the asymptomatic testis because of the normal "low-flow" state of the testis. Therefore, the diagnosis of acute torsion cannot be made with sonography, and either scintigraphy or immediate surgical exploration is warranted. This situation is more likely in the prepubertal testis because of its smaller size and lesser blood flow compared with the postpubertal testis. Intrascrotal hydrocele is a potential pitfall for nuclear scintigraphy. When a central photopenic region is seen, transillumination of the scrotal contents or sonography is needed to distinguish between hydrocele and acute testicular torsion. A pitfall that occurs with sonography and scintigraphy in the diagnosis of testicular torsion is
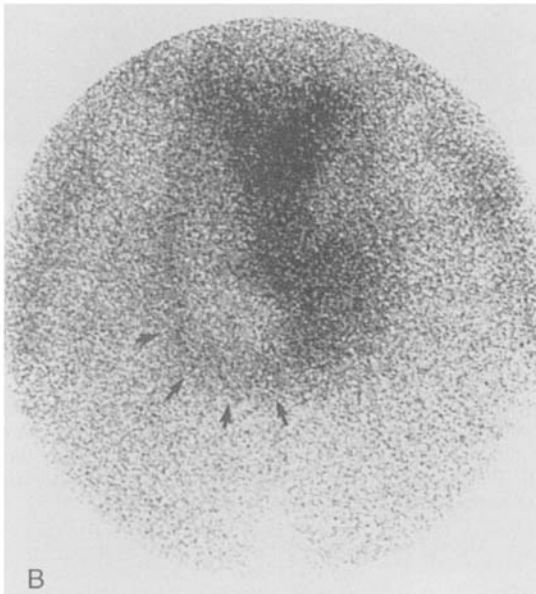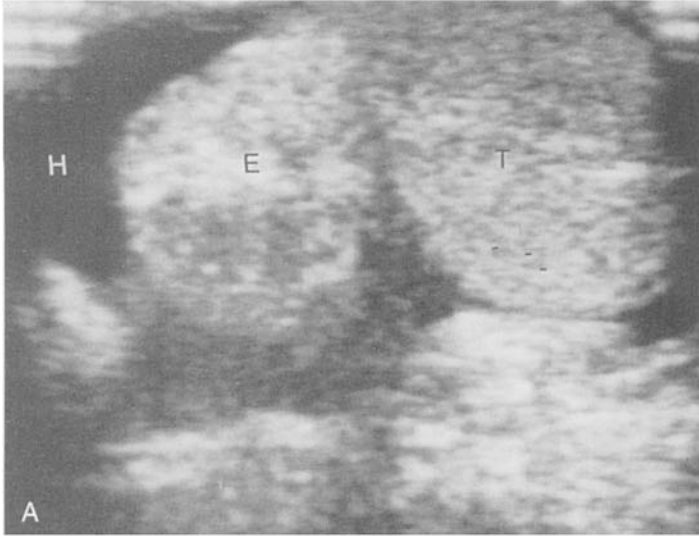
Figure 7. Acute testicular torsion in a 12-year-old boy with acute onset right scrotal swelling for 4 hours. *A,* Sonogram showing marked enlargement of epididymis (E) and hydrocele (H). No color flow was present in the epididymis or testis (T). *B,* Scintigram showing photopenic defect in right hemiscrotum *(arrows).* The left hemiscrotum shows normal flow.
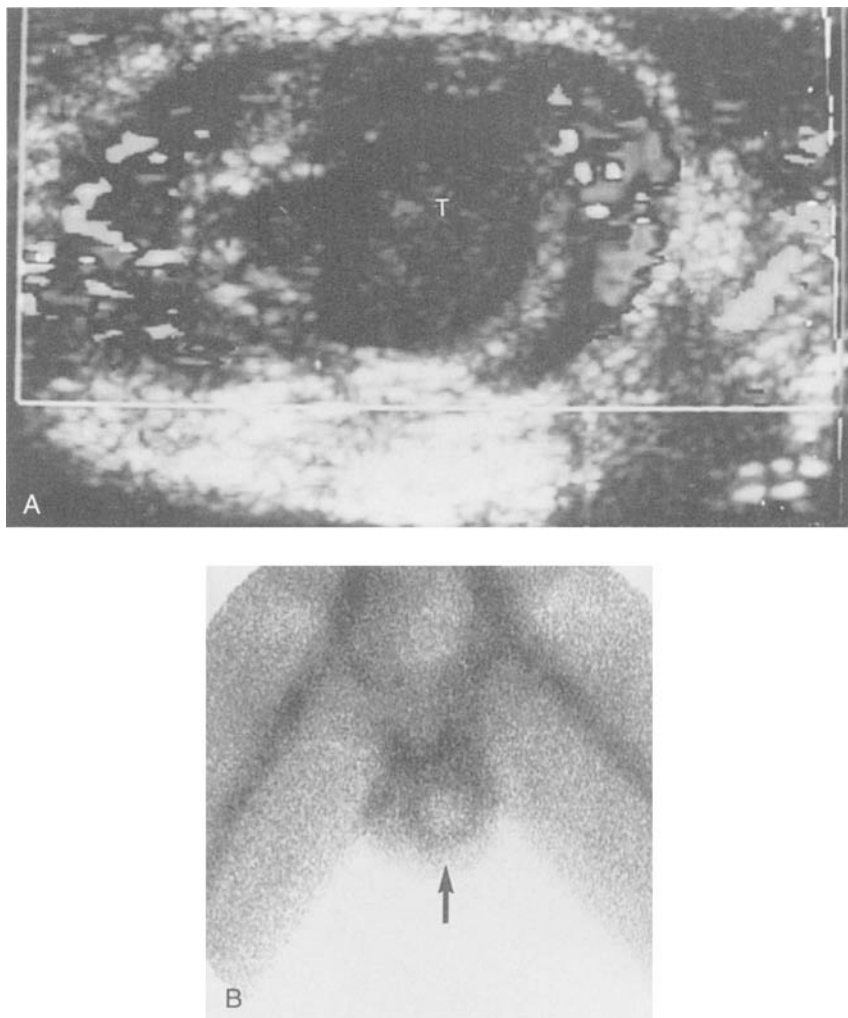
Figure 8. Late phase testicular torsion in a 5-year-old boy with 1-day history of left scrotal pain and swelling. "Doughnut Sign." *A,* Color Doppler sonogram shows absent intratesticular blood flow and a markedly hyperemic rim evidenced by blue and red color flow (T = testis). *B,* Scintigram shows photopenic central region on left with increased peripheral flow in the surrounding scrotal wall *(arrow).*

spontaneous detorsion or intermittent torsion.[7, 40] In this situation, the blood flow may be normal, increased, or decreased. Correlation with the patient's clinical history is crucial; an acute resolution of pain should raise the suspicion of spontaneous detorsion. Another potential pitfall for both modalities is incomplete torsion, when the blood flow may be normal or decreased.[7, 40]

Epididymitis

Epididymitis may be infectious, traumatic, or reactive.[15] Although epididymitis occurs most frequently in sexually active boys older than 13 years of age, it is not uncommon in infants and children.[15, 26] The hallmarks of epididymoorchitis are hyperemia and enlargement (Fig. 9).
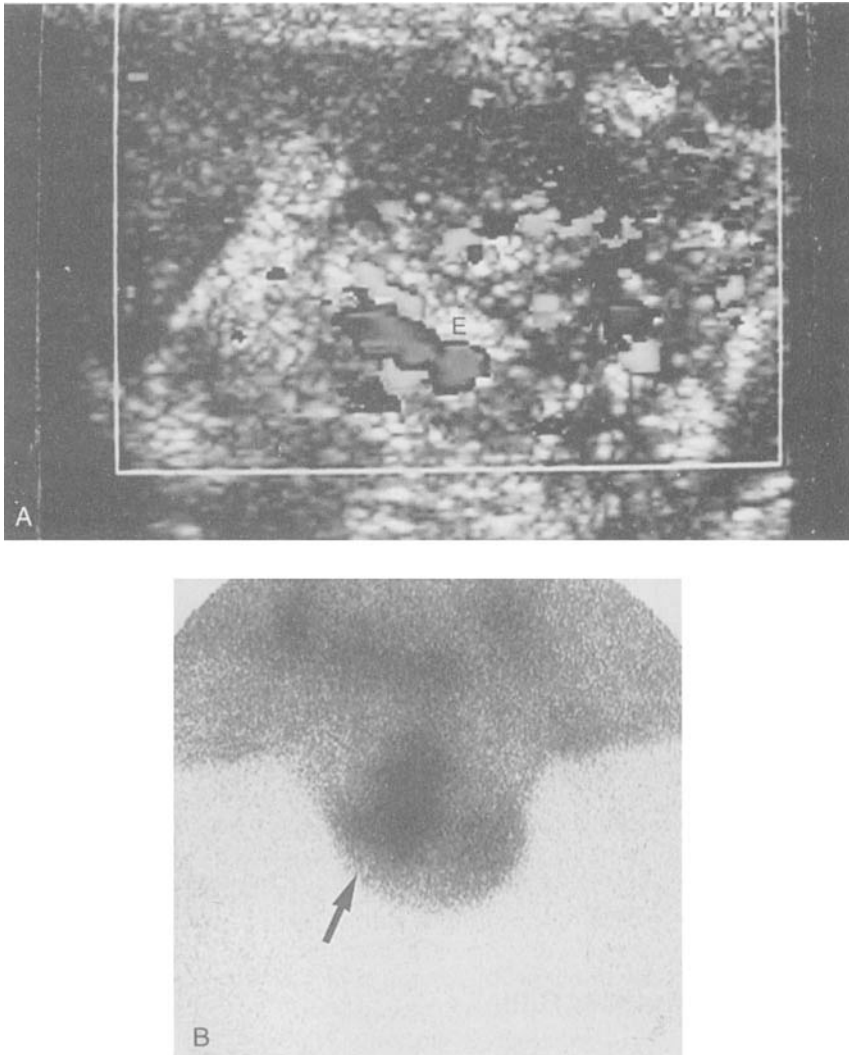

Figure 9. Epididymoorchitis in a 15-year-old boy with right scrotal pain, swelling, and redness. *A,* Color Doppler sonogram shows increased size and color flow in the right epididymis (E). *B,* Scintigram shows markedly increased flow in the right hemiscrotum *(arrow).*

A reactive hydrocele is frequently present.[17] The kidneys should also be examined in prepubertal boys as an associated genitourinary abnormality, such as a duplex collecting system with ectopic ureteral insertion into the vas deferens, or seminal vesicles may be present.[17] Potential complications include testicular abscess and testicular ischemia with postinflammatory infarction. Children with Henoch-Schönlein purpura and painful scrotums show sonographic findings identical to infectious or reactive epididymitis.

Torsion of Appendix Testis

Torsion of the appendix testis, a vestigial structure superior to the testis, occurs most frequently in patients between the ages of 3 and 13 years. It results in hyperemia of the testis and epididymis and epididymal enlargement, with sonographic findings usually indistinguishable from epididymoorchitis.[11] An echogenic mass superior to the testis has been reported.[6] Nuclear scintigraphy shows focal or diffuse increased flow.[23]

Testicular Trauma

Testicular trauma can result in a testicular contusion, hematoma, or laceration.[17] On sonography, intratesticular hematoma results in an echogenic or hypoechoic testicular mass.[17] In contrast, a hematocele results in a complex extratesticular fluid collection.

Testicular Neoplasms

Testicular neoplasms occur in prepubertal and postpubertal boys and result in a painless, unilateral testicular mass.[17] Leukemic infiltration results in bilateral testicular enlargement. Germ-cell tumors comprise most (70–90%) testicular tumors.[17] In prepubertal boys, teratomas and yolk sac tumors are the most common tumors. The sonographic hallmark of an intratesticular mass is hypervascularity, either focal or diffuse.[17] The tumor may show as a focal hypoechoic or hyperechoic mass or a diffusely enlarged testis.

CHILDREN WITH HEMATURIA

Several pathologic processes can cause hematuria in children. Bleeding may originate in the renal parenchyma, intrarenal collecting system, ureter, or the bladder. Although occasionally the cause of the hematuria is diagnosed on clinical basis alone, imaging often is needed for identifi-

cation of the underlying cause. Some common causes of hematuria, UTI, inflammation, trauma, neoplasm, and stones are discussed.

Trauma and Infection

Two of the most common causes of pediatric hematuria, trauma and UTI, have been discussed previously and, therefore, are briefly mentioned at this point. UTIs can cause hematuria in addition to the more common symptoms of fever and dysuria. Hematuria tends to be a more prominent feature of infection directly involving the collecting system or lower urinary tract. Tuberculosis and fungal processes have a tendency to involve the collecting system and are more common in immunocompromised patients. Sonography is the best imaging modality to evaluate for fungus balls in the upper collecting system and bladder. Many forms of cystitis can be hemorrhagic, including bacterial, viral, and parasitic (Schistosoma hematobium) cystitis. Other causes of cystitis are iatrogenic, including cyclophosphamide or radiation-induced cystitis. Sonography also can be used to evaluate for the presence of blood clots and bladder wall thickening from the cystitis. The lower urinary tract also may be studied with VCUG if further delineation of the bladder wall is needed. Trauma at any level of the genitourinary tract may cause hematuria, and CT is the study of choice in severe trauma.

Calculi

Urolithiasis occurs in less than 0.1% of children and is an important cause of hematuria.[10] If the stone becomes impacted in the ureter and causes obstruction, abdominal pain also may be present. Most calculi are found in the kidneys, ureter, or both.[10] Conditions predisposing to calculi in children include UTI; urine stasis; congenital urinary tract anomalies; abnormal urine pH; immobilization; steroid or diuretic therapy; and metabolic abnormalities, such as hypercalcemia, hypercalciuria, hyperoxaluria, uricosuria, cystinuria, xanthinuria, and renal tubular acidosis. Abdominal radiography is the initial study of choice in patients with suspected urolithiasis. Stones at all levels from the kidneys to the bladder are potentially seen if adequately calcified. Approximately 85% of urinary tract stones are calcified. If no stones are seen on plain radiography, sonography of the kidney and bladder or intravenous urography should be performed. Sonography also can detect hydronephrosis and hydroureter, which may be present secondary to obstruction by the stone (Fig. 10). Small parenchymal calculi and nephrocalcinosis are also well detected with sonography; however, intravenous urography is the study of choice for suspected obstructing ureteral calculi, particularly when no calculi are seen on radiography or sonography. Renal functional information also can be obtained with intravenous urography. Recently, noncontrast CT scanning has been used to diag-
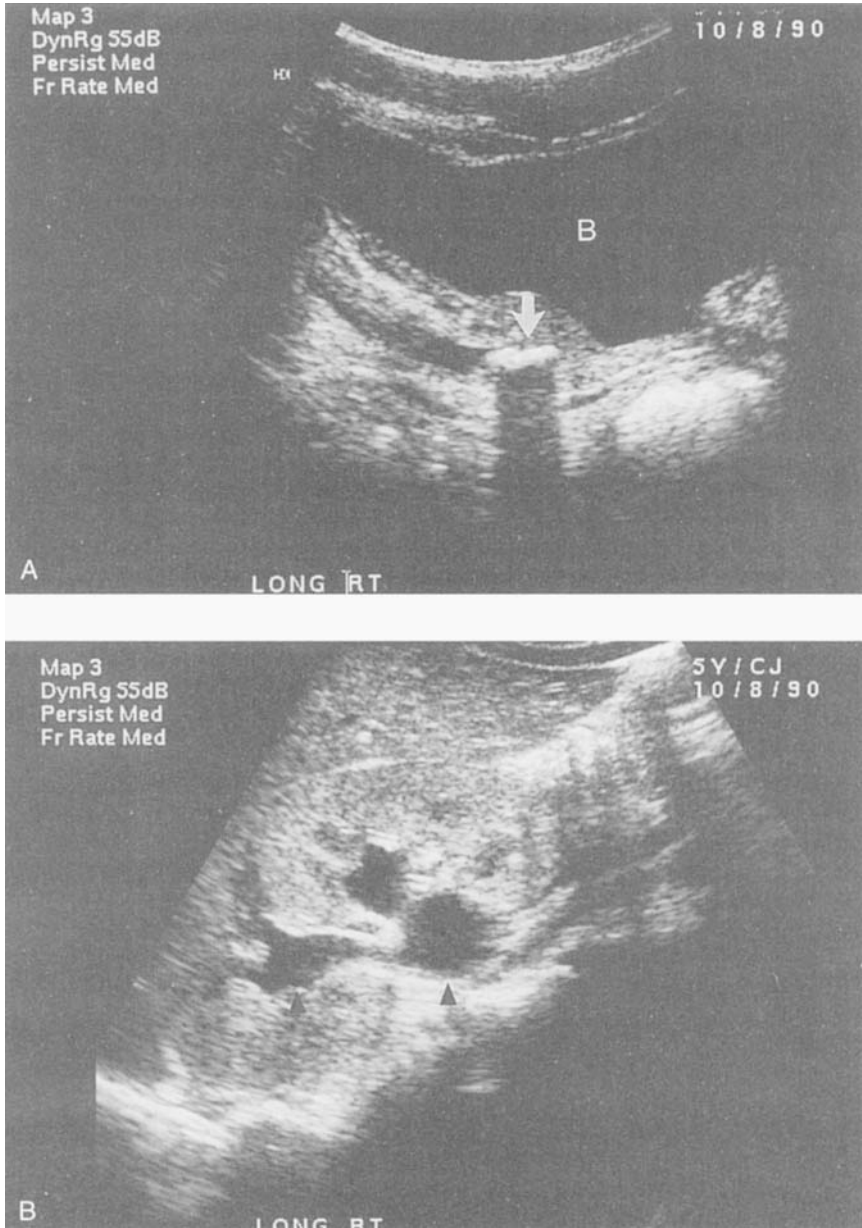
Figure 10. Ureteral calculus with secondary obstruction in a 6-year-old boy with abdominal pain and hematuria. *A,* Sonogram shows echogenic calculus with shadowing *(arrow)* in distal right ureter with proximal ureteral dilatation (B = bladder). *B,* Sonogram of right kidney shows dilatation of collecting system *(arrowheads)* secondary to obstruction by distal ureteral calculus.

nose renal calculi and secondary obstruction.[28] CT may be even more sensitive than sonography in detecting renal calculi.

Neoplasms

Genitourinary tract neoplasms may cause hematuria by involvement of the collecting system or lower urinary tract. Sonography of the kidneys and bladder initially should be performed to identify a urinary tract mass; however, CT or MR imaging is required for complete delineation and detailed assessment of solid genitourinary masses. Rhabdomyosarcoma, the most common lower urinary tract malignancy in children, often causes hematuria usually associated with straining to void or dysuria.[38] Renal neoplasms, such as Wilms' tumor and, less commonly, renal cell carcinoma may cause hematuria, although they more often present with an abdominal mass.

SUMMARY

A multitude of disorders of the genitourinary tract can occur in children. Although some entities may be diagnosed clinically, radiologic imaging is often necessary for diagnosis and management. The radiologic work-up has been discussed using a problem-oriented approach in five clinical situations: urinary tract infection, hydronephrosis or hydroureter, trauma, swollen scrotum, and hematuria. This discussion provides some general guidelines, although the evaluation of each child may need to be individualized depending on their specific clinical symptomatology.

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