ADVANCES IN THE IMAGING OF RENAL INFECTION

Helical CT and Modern Coordinated Imaging

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In recent years, computed tomography (CT) has increased in prominence in the imaging and evaluation of renal infection. The reasons for this trend include better availability of CT scanners and timely access to them. Additionally, important technical advances have made CT studies easier to perform and have increased the reliability and utility of the information that they provide. Other imaging modalities, namely, ultrasound (US), nuclear scintigraphy, excretory urography (IVP), and MR imaging have varying degrees of usefulness in the evaluation of renal infection.

Diagnostic imaging is not required in all cases of renal infection. For example, in most cases of acute renal infection in adults, the diagnosis and treatment may be based solely on clinical and laboratory findings. This article discusses what helical CT and other imaging has to offer, including the specific roles, capabilities, and limitations of the various imaging modalities. Individual disease entities are then discussed, with particular attention to imaging findings that are characteristic or that have significance with regard to patient management.

COMPUTED TOMOGRAPHY

CT offers excellent images of the renal parenchyma and the surrounding tissues. The energy of the radiation beam is relatively high compared with that used in plain film radiographs. As a result, structures on a CT image assume a
density that is proportional to their specific gravity. For quantification purposes, air has arbitrarily been assigned the value of \(-1000\) Hounsfield units (HU) and water assigned a value of 0 (practical range \(-20\) to \(+10\)). Compared with water, fat is less dense and generally corresponds to \(-30\) HU or less. Somewhat higher in attenuation are muscle and solid organs (30 to 60 HU) and bone (generally above 300 HU).

The density of normal, unenhanced renal parenchyma is approximately 30 to 50 HU and probably varies with the state of hydration.\(^{22}\) The CT density is roughly comparable to skeletal muscle. The parenchyma should normally appear entirely homogeneous, with the exception of a faint ill-defined increase in attenuation noted in the parenchyma nearest the hilum.\(^{15}\) This is generally visible only on narrow window settings. The kidneys are sharply defined against the low density retroperitoneal fat. Within this fat, the perirenal (Gerota) fascia is visible as a thin line encircling the kidney in the axial plane (see Fig. 4). Multiple thin lines within this circle, which further subdivide the perirenal space, are known as bridging fascia. Inflammatory processes declare themselves as these normally thin fascial lines become thickened. Knowledge of these fascial planes and the compartments they delineate allow for localization of retroperitoneal inflammatory processes to the organ of origin.

Intravenous contrast may be administered to enhance the density of vascular tissues in general. Both ionic and nonionic formulations are available and both contain iodine as the active ingredient. Both carry a risk for severe allergic reaction with a mortality rate of approximately 1 per 100,000 administrations.\(^4\) Nonfatal allergic reactions are considerably more common, particularly with ionic contrast media. Nephrotoxic effects are also possible and are avoided or mitigated by good hydration. In general, organs opacify with IV contrast in proportion to their degree of vascularity. The kidneys are extremely vascular structures. The kidneys, however, concentrate IV contrast, and thus normally opacify to a greater degree than any other solid organ.

The kidneys may be scanned without contrast, a phase that best discriminates different types of solid tissue, such as fat and soft tissue, from one another and is ideal for the identification of calcifications in the renal parenchyma or ureter. When contrast medium is used, the kidneys can be scanned multiple times on the same bolus injection because of the speed of helical scanning. Each time the kidneys are scanned, it is considered to be a "phase." Although many phases are possible, two besides noncontrast scanning are typically used in the evaluation of renal infection: the cortical phase and the parenchymal or excretory phase.

The cortical phase, also known as the portal venous phase, is typically obtained 70 seconds after the beginning of the contrast medium injection. In the cortical phase, the cortex contains contrast, whereas the pyramids do not. There is excellent filling of the venous and arterial structures (Fig. 1). This phase is standard on CT of the abdomen because it is present during the time when liver scanning must be done to avoid missing liver lesions.

The parenchymal or excretory phase occurs 2.5 to 3 minutes after the beginning of the injection. At this time, corticomedullary definition is no longer present and the entire parenchyma is uniformly enhanced. The uniform enhancement of the renal parenchyma permits detection of parenchymal lesions, including infection, cysts, and tumors—any lesion that does not enhance with the same extreme intensity of normal functioning renal tissue. Excretion of contrast media into the collecting system occurs during this phase.

At the authors' hospital, both phases are routinely performed by the authors on all patients. By combining the information on these phases, a specific diagno-
sis is often possible that would not be obtained on one phase alone. This is the equivalent of combining information on different imaging studies (see later discussion).

Contrast administration reveals avascular structures as showing no change in density when precontrast and postcontrast images are compared. Visual evaluation of images may be supplemented by direct measurement of attenuation values. In the kidney, avascular areas correspond to cysts, abscesses, necrotic tumors, or infarcts. Contrast administration also offers a measure of the kidneys' concentrating abilities. Kidneys affected by acute pyelonephritis commonly appear normal or nearly so on noncontrast images; administration of contrast will reveal a patchy or linear opacification pattern, reflecting the unequal effects of the infection on the renal parenchyma.

**Helical Computed Tomography**

Since its application to abdominal imaging in the 1970s, CT studies continue to assume the same basic format—individual axial images. Although the basic image layout and appearance has changed little over the years, technical advances continue to have a profound impact. Most recently, helical CT has revolutionized the method by which the images are obtained. Although a helix is not the same as a spiral, the terms *helical CT* and *spiral CT* are synonymous (Fig. 2). Different manufacturers use one or the other phrase to describe their equipment.

In a conventional nonhelical scanner, each image is obtained individually. To do this, the table is set to a specific position, the patient is instructed to hold his or her breath, the radiograph source and detectors rotate a full 360° around the patient as the data is obtained, the patient is instructed to breathe, and the table is moved to the next position in which the process is repeated. With helical scanning, the table holding the patient is advanced at a constant rate while the scan is performed. Because the patient is constantly in motion during the data acquisition, no true axial scan is obtained. Instead, a helical column of data is acquired. Axial images are then reconstructed by interpolation to create the axial image. Each individual axial image obtained using helical technique is essentially indistinguishable from a nonhelical image.

Despite the fact that the individual images are not appreciably different, helical CT has considerable advantages over conventional CT. Because the data column is continuously obtained, skip areas are eliminated in helical CT. Conventional CT has been plagued by “misregistration artifacts.” With conventional scanners, even the most cooperative patients might take unequal breaths between slices, resulting in uneven slice selection. Smaller lesions are particularly susceptible to being misrepresented or even missed altogether. Helical scanners create a continuous column of data so that axial images can be reconstructed and portrayed at precise intervals. Small lesions are reliably included within the limits of resolution and slice thickness.

The continuous data column also has other advantages. Because the axial image is essentially an artifact created by data from other planes, other axial images at different levels (“between the slices”) can be created. Creating these overlapping images after the initial images have been obtained is known as refocusing. Thus, scans made with a slice width of 10 mm can be refocused every 1 mm to obtain a more detailed picture. Because the original column of data is in three dimensions, images may be made (“reconstructed”) in planes other than axial or in three dimensions.
Figure 1. Sequential images following intravenous contrast administration. A, Precontrast image, ideal for detection of calculi, calcification, and hemorrhage. B, Approximately 30 seconds following IV bolus administration, contrast is present in arteries, but veins are as yet unopacified. Contrast opacification is much greater in renal cortex compared to medulla. Note densely opacified aorta (A) compared with cava (C).

Illustration continued on opposite page

Helical scanning has increased considerably the speed of image acquisition. With conventional scanners, the rate at which a patient on the table could be repeatedly moved and then stopped for scanning was limited by patient comfort to a surprisingly slow overall speed. Because the patient is in constant motion with helical technique, scanning speed is limited only by the equipment. The increased speed has markedly improved the use of IV contrast. Prior to helical scanning, the speed of data acquisition was such that, by the time the lower abdomen was imaged, the optimal phase of enhancement had passed. To compensate somewhat, contrast was administered at a slow, continuous rate. Administration of contrast in this manner blended the various phases and decreased tissue contrast but saved some IV contrast for the later images. The speed of helical scanning allows for contrast administration as a single, rapid bolus. The increased rate of contrast administration creates much greater tissue contrast.
Figure 1 (Continued). C, At approximately 2 minutes, cortex and medulla are uniformly opacified. Standard "portal venous phase" images are obtained at an intermediate time between images B and C, although corticomedullary differentiation is still present. D, At approximately 3 minutes, contrast is present in renal collecting systems (curved arrows). Peripherally located renal cell carcinoma (arrows) enhances with contrast but to a lesser degree than functioning renal parenchyma. Note how a similar lesion, if located more centrally within the medulla, may be missed on early images.

Additionally, images may be obtained during the specific desired phase of contrast enhancement. Moreover, the rapidity and ease of helical image acquisition have made it possible for multiple phases of contrast enhancement to be imaged during a single study. On all routine abdominal CT studies at the authors' institution, the kidneys are imaged in two different phases of contrast enhancement.

A hallmark of acute pyelonephritis is that the visualized abnormality covers different territories on different imaging studies. For example, the size and extent of the abnormality seen on CT scan may be different from that of the abnormality seen on US or nuclear scintigraphy. This is often an important feature in distinguishing pyelonephritis from neoplasm. The authors have also noted acute pyelonephritis to be different in size on different phases of contrast enhancement within the same CT study (Fig. 3). This is not surprising because
as noted previously, the different phases are essentially different studies. Thus, the entire kidney may be involved on one phase of the study and focal abnormalities identified on another phase.

Contrast-enhanced helical CT has become the major initial study in acute renal infection. This is because it has significantly greater sensitivity than gray scale ultrasonography or the IVP with nephrotomography in identifying renal parenchymal abnormalities in acute pyelonephritis. CT is also far more successful than any of these techniques in identifying perinephric fluid collections. Finally, small stones that may be playing a role in the cause of the infection are easier to identify on CT than competitive techniques. Thus, if a single test is going to be used to evaluate patients who are thought to have acute renal infection and its complications, it is currently helical CT.

Noncontrast Helical CT

In 1995, helical CT without oral or intravenous contrast was demonstrated to be a highly effective means to confirm or exclude the presence of obstructing ureteral calculi. Since that time, noncontrast helical CT (NCCT) has been used increasingly to evaluate patients with flank pain and suspected renal colic. Among the many features favoring the new method, the lack of intravenous contrast avoids the risks for contrast allergy and contrast-induced nephrotoxicity. Without the need for oral or intravenous contrast, images may be obtained rapidly and with minimal patient preparation. The speed at which the study is completed is a marked improvement on excretory urography, which may require several hours in the setting of obstruction. Although billing and reimbursement may vary, the net marginal cost of obtaining NCCT is less than that of excretory urography. Moreover, NCCT has been demonstrated to have an accuracy of 97% in the detection of ureteral calculi. Not only is NCCT highly accurate in detecting the presence of obstruction, but also in virtually all cases
Figure 3. Acute pyelonephritis, left kidney. A, On noncontrast images, left kidney appears normal. Note small stone on right side (arrow). B, Cortical phase of intravenous contrast enhancement reveals focal enhancement irregularity of left lateral parenchyma (arrowhead). C, Diffuse enhancement abnormality involving entire left kidney is more obvious on delayed images. For comparison, right kidney enhances normally.

allows determination of the size and position of the obstructing calculus. This is of considerable use in planning subsequent patient management.

Among emergency room patients with flank pain and suspected renal colic, approximately half actually have an obstructing calculus. Of the remaining half, the patients' symptoms may be caused by a multitude of other causes, including appendicitis, pelvic masses, and cholecystitis. In these patients, NCCT often demonstrates the underlying cause for the patient's discomfort.

Of this group of patients presenting with suspected renal colic, a small but
significant percentage instead have acute pyelonephritis. Compared to renal colic, acute pyelonephritis is a much less common entity. Acute pyelonephritis has certain imaging features that are best evaluated with IV contrast and are discussed in a subsequent section. Without contrast administration, however, the recognition of these patients can be difficult. The deserved increasing popularity of NCCT in the evaluation of acute flank pain has created a potential pitfall. To avoid this pitfall, it is important to understand how these studies are interpreted.

In the diagnosis of renal colic, the single most reliable sign is the visualization of the obstructing calculus within the ureter (Fig. 4). This can be done in most cases. Essentially all renal calculi are sufficiently radiopaque to be visible on standard CT images. In addition to the direct visualization of the obstructing stone, other secondary signs are often used. These include perinephric stranding, collecting system dilatation, and enlargement of the affected kidney. The first two of these signs, when both are present, are highly accurate in detecting renal

Figure 4. Helical noncontrast CT scan to evaluate renal colic. A, Perinephric stranding surrounding left kidney accentuates Gerota’s fascia (arrows). Left renal pelvis (hollow arrow) is mildly dilated. B, A few centimeters below, the obstructing calculus (curved arrow) is seen at level of the ureteropelvic junction.
obstruction. When both are absent, these two signs are also highly accurate in excluding renal obstruction. Thus, the presence of these secondary signs in the absence of direct stone visualization may justifiably lead to the diagnosis of obstruction by a nonvisualized stone, or perhaps a recently passed stone.

Perinephric stranding, collecting system dilatation, and renal enlargement, however, are all seen in varying frequency on NCCT in patients with acute pyelonephritis. In general, the differentiation between renal colic and acute pyelonephritis is made by finding pyuria in the latter, but hematogenous spread of infection may not produce pyuria. In a patient with flank pain who does not have nephrolithiasis and if renal infection is in the differential diagnosis and any of these findings are identified, contrast CT is needed for definitive diagnosis. The contrast medium can be injected with the patient still on the table, and the answer should be apparent in minutes. An added advantage of using contrast CT is that nonrenal disease also may be more apparent with contrast medium.

The findings on noncontrast CT associated with acute renal infection are nonspecific. Perinephric stranding is a nonspecific finding. When unilateral, the presence of perinephric stranding tends to indicate acute urinary tract stone disease or other acute urinary tract abnormality such as pyelonephritis; however, this is not always true. Previous insults to the kidney, including trauma, infection and vascular disease, also lead to increased perinephric stranding, which usually persists over time. Thus, perinephric stranding should be regarded as a useful but not definitive indicator of acute renal abnormality in a patient with acute symptomatology.

Similarly, ureterectasis (dilatation of the ureter) may be caused by acute obstruction, such as from nephrolithiasis, or it may be caused by acute pyelonephritis. Ureterectasis may be present secondary to previous obstruction (including pregnancy), vesicoureteral reflux, or primary megaureter, however. The authors have seen all of these causes in the 800 cases over the past 3 years that have presented to our institution with flank pain.

Unilateral nephromegaly is also nonspecific. The most common normal variant that causes nephromegaly is a duplicated collecting system. In addition to acute pyelonephritis, other entities such as unilateral medullary sponge kidney are associated with unilateral nephromegaly. Thus, this finding alone also is not sufficient to assume there is urinary tract abnormality; however, the clinical picture including laboratory findings combined with the imaging findings can generally lead one to the correct next diagnostic test, if one is indicated.

ULTRASOUND

Ultrasound permits direct visualization of the renal parenchyma in real-time with multiplanar ability. Structures are visible by the degree to which they reflect or attenuate ultrasonic waves. The kidneys are visible as moderately echogenic structures against a background of generally more echogenic retroperitoneal fat. Echogenic structures and distance from the ultrasound transducer attenuate the ultrasound beam and decrease image quality. Thus, imaging of obese patients is often difficult. This is in contrast to CT, where fat is often helpful in delineating and separating solid structures. Sonography has the potential for higher resolution than CT; that is, it can separate smaller structures. Tissue contrast, and not resolution, is usually the limiting factor, however. Sonography is less sensitive than CT in evaluating acute pyelonephritis.

Sonography is generally sensitive to the physical state of the structure
imaged. Pure liquid does not appreciably reflect the beam and thus appears anechoic. Sonography may quite exquisitely demonstrate small septations or particles of debris against a background of anechoic fluid. Solid, hard structures reflect the beam and block its transmission through deeper tissues. Thus, stones are often visible not only by their echogenicity, but also by the dark shadow that they produce. Likewise, air disperses the beam and is visible largely by the artifact that is produced, a gray or "dirty" shadow.

By measuring the difference in frequency between the beam emitted and the beam received (the Doppler effect), calculation of velocity is possible. This is of particular use in detecting and measuring vascular flow. Moreover, the real-time, multiplanar capability is particularly useful in guiding interventional procedures.

**NUCLEAR MEDICINE**

Diagnostic radiology encompasses images obtained from radiation (or other energy sources) located outside the patient. On the other hand, nuclear medicine involves images obtained from sources of radiation administered intravenously, orally, or otherwise within the patient.

Numerous radionuclides have been used to evaluate the urinary tract. The most common examinations use radiotracers designed to evaluate renal function. These substances are imaged and quantified as the radioactivity reaches the kidney by way of the arterial supply, is taken up by the renal cortex and travels through the tubules, and is excreted into the upper collecting systems and eventually the bladder. These radiotracers include Hippuran, diethylenetriaminepenta-acetic acid (DTPA), and, most recently, MAG3. The intravenous contrast used in excretory urography or CT offers a similar estimation of renal function, although nuclear medicine offers the advantage of more absolute quantification. Because these radiotracers are designed to be readily excreted, they offer relatively limited, transient evaluation of the renal parenchyma.

DMSA is a radiotracer that localizes to the renal cortex by binding to sulfhydryl groups in the proximal renal tubules. Forty-two percent of the injected dose remains in the renal cortex at 6 hours. As a result, DMSA offers a rather poor estimation of renal function; however, compared with the above-mentioned radiotracers, DMSA offers relatively high resolution images of the renal cortex. Acute pyelonephritis appears as a defect in DMSA uptake, or as patchy or decreased uptake. DMSA is sensitive in detecting abnormalities in kidneys affected by acute pyelonephritis and may be slightly more sensitive than CT. Imaging with DMSA has considerable drawbacks, however. Although resolution is better than that obtained with the functional radiotracers, the anatomic detail leaves much to be desired. DMSA does not evaluate extrarenal extension of disease. It is not possible to distinguish whether or not abscess is present. And because the radiotracer remains bound to the renal cortex, radiation dose to the kidneys is relatively high.

Renal infections may also be detected with radiotracers designed to concentrate in areas of inflammation or infection. Indium-labeled white blood cells can yield results within 24 hours; however, the white blood cell labeling procedure is time-consuming, expensive, and fraught with medicolegal risk. As a result, the study is not available at many institutions. Gallium is easier to administer, but results take considerably longer. Imaging within 24 hours following administration is not worthwhile because of normal renal excretion of the radiotracer. After 24 hours, imaging may be complicated by normal activity in overlying
colons. Neither gallium nor indium can distinguish pyelonephritis from an abscess. Gallium is, in addition, taken up by certain neoplasms, and therefore cannot distinguish infection from neoplasm.

**MR IMAGING**

The role of MR imaging in the evaluation of renal infection has yet to be established. In the meantime, it can be assumed that gadolinium-enhanced MR imaging can perform similarly to contrast-enhanced CT. MR imaging, therefore, may be considered as an alternative in the case of patients with contraindications to iodinated contrast administration.

**ACUTE RENAL INFECTION**

**Acute Pyelonephritis**

The meaning of the word *pyelonephritis* is, literally, an inflammatory process involving the kidneys and pelvis. Bacteria are responsible for most acute cases, and so *acute pyelonephritis* and *acute bacterial pyelonephritis* are often synonymous. The Society of Uroradiology prefers the latter. Focal manifestations of acute pyelonephritis have been called *lobar nephronia* in the past. The term *nephronia* can be thought of as analogous to pneumonia.

Most acute bacterial infections reach the kidneys by an ascending route. This is particularly true in children. The most common pathogens are gram negatives such as *Escherichia coli*, reflecting the perineal source. Infection may also reach the kidney by a hematogenous route, in which case *Staphylococcus* is the most common pathogen. Individuals with bacteremia or immune dysfunction are understandably at increased risk. Urinary tract obstruction greatly increases the susceptibility of the renal parenchyma to bloodborne pathogens.

In adults, uncomplicated acute renal infections do not require radiologic workup. Management may often be based on clinical and laboratory findings. Radiologic workup is useful when the diagnosis is in doubt, in severely ill or immunocompromised patients, in those who fail to improve on antibiotic therapy, or when complications are suspected. The radiologic study of choice is contrast-enhanced CT scan.

Contrast-enhanced CT is highly sensitive in the detection of acute pyelonephritis, and is probably abnormal in all but the mildest cases. A common finding is decreased opacification of the affected renal parenchyma, typically in patchy, wedge-shaped or linear patterns (Fig. 5). The different patterns may coexist; the thinner linear pattern is often seen within the larger wedge-shaped defects. Both the wedge-shaped and linear-enhancement defects are seen to radiate outward from the pelvis to reach the capsular surface. This pattern results from differential obstruction of groups of collecting tubules with resulting dysfunction. As mentioned previously, parenchymal abnormalities may be different sizes on different phases of enhancement (see Fig. 1).

Noncontrast CT is often normal but may show focal areas of slightly decreased attenuation. Areas of markedly decreased attenuation should raise the suspicion of abscess formation; contrast should, if possible, be administered in such instances.

Other CT findings are common to both contrast-enhanced and noncontrast studies. Affected kidneys may be enlarged diffusely or focally; focal enlargement
Figure 5. Acute pyelonephritis. Unusually dramatic example of striated nephrograms seen in early pyelonephritis, typically in cases in which infection occurs by way of an ascending route. Note also bilateral renal enlargement (nephromegaly).

may occasionally be mistaken for a mass. Perinephric stranding is visible in the surrounding fat (Fig. 6) and does not necessarily indicate extrarenal spread of infection. Mild collecting system dilatation may be present.

Excretory urography, known also as IVP, is relatively insensitive to acute pyelonephritis, showing abnormalities in approximately 25% of cases, typically the most severe.9 Findings include focal or global renal enlargement or focal or global regions of nonexcretion. The defects may be wedge-shaped or linear, the urographic equivalent of the distinctive CT patterns.

Likewise, sonography is relatively insensitive to acute pyelonephritis and will be normal in most uncomplicated cases.27 Findings when present include focal or global renal enlargement, compression of the renal sinus or blurring of its borders, and ill-defined zones of decreased attenuation within the renal parenchyma. The combination of a hypoechoic region with a focal bulge may be confused with neoplasm.

A hemorrhagic form of acute pyelonephritis has been described, with distinct findings on noncontrast CT and sonography.18 On noncontrast CT, hemorrhagic areas are visible as areas of increased attenuation. Sonography may reveal regions of increased echogenicity within the parenchyma (Fig. 7). Contrast-enhanced CT findings of hemorrhagic acute pyelonephritis are similar to those of classic acute pyelonephritis.

In moderate and severe cases of acute pyelonephritis, CT scan abnormalities usually persist for several weeks, well after the clinical symptoms and laboratory findings have returned to normal.37 Following adequate treatment, most cases will eventually show complete resolution of imaging abnormalities. In some cases, especially those in which chronic reflux is associated with recurrent episodes of infection, the affected renal lobes undergo typical changes of reflux nephropathy, formerly known as chronic atrophic pyelonephritis.10 Recurrent infections result in deformity and dilatation of calyces and focal cortical loss, which is most severe in those areas of cortex nearest calyces (Fig. 8). Classically, upper and lower poles are most severely affected.
Figure 6. Acute pyelonephritis, noncontrast CT. A, Prominent stranding is noted in the fat surrounding the left kidney. B, In another patient, nephromegaly is the most prominent feature. Perinephric stranding and nephromegaly are nonspecific findings, and in the proper clinical setting, intravenous contrast may be administered to confirm the diagnosis.

Abscess

Frank abscesses in the renal parenchyma are not common but do occur as a complication of acute pyelonephritis. When severe, acute pyelonephritis may contain small areas of necrosis and microabscess formation. These areas may enlarge or coalesce to form larger lesions and proceed to liquefaction. Some investigators have suggested that a continuum between acute pyelonephritis and abscess exists, with a potentially reversible preabscess state. Abscesses are typically seen with cases of infection by way of a hematogenous route or in cases complicated by urinary obstruction.

On contrast-enhanced CT, the hallmark of an abscess is a focal area that fails to enhance to even the slightest degree, indicating an avascular state.
Figure 7. Hemorrhagic focal acute pyelonephritis. A, Longitudinal sonogram of the right kidney shows an echogenic area of parenchyma in a patient with signs and symptoms of acute urinary tract infection in the upper pole (arrows) (K = kidney, L = liver). B, Noncontrast CT image of the kidneys with narrow window shows the same area of parenchyma with increased density (arrow) indicating recent hemorrhage (K = kidney, L = liver). (From Rigsby CM, Rosenfield AT, Glickman MG, et al: Hemorrhagic focal bacterial nephritis: Findings on gray-scale sonography and CT. Am J Roentgenol 146:1173–1177, 1986; with permission.)
Abscesses are typically well defined, round or ovoid, and contain a low-density center (Fig. 9). Abscesses are typically sharply demarcated, which helps to distinguish them from more poorly defined areas of focal pyelonephritis. The presence of fluid density (0 to 20 HU) confirms liquefaction, although the high protein content of pus may yield higher density values.

In contradistinction to pyelonephritis, abscesses may be well evaluated by ultrasonography. The sharp demarcation and presence of liquefaction match the strengths of the imaging modality. The sonographic appearance of intrarenal abscesses is variable. Abscesses may lack internal echoes and mimic cysts. Debris within abscesses may be mildly, moderately, or markedly echogenic. Echogenic debris may be visible in dependent portions and may be seen to shift as the patient is repositioned.
Pyohydronephrosis (Pyonephrosis)

Pyonephrosis is infection of an obstructed renal collecting system. Pyonephrosis represents a severe complication of hydronephrosis that requires prompt diagnosis and treatment to prevent progressive, permanent loss of renal function. Instead of pyonephrosis, the term pyohydronephrosis has been used and is superior in that it is more descriptive and less apt to be confused with pyelonephritis.

Pyohydronephrosis may complicate urinary tract obstruction of any cause. Half of cases are associated with obstructing calculi; other causes for the underlying obstruction include strictures, congenital anomalies, and neoplasms (Fig. 10). Pyohydronephrosis is more likely to occur in cases of chronic obstruction. Although a variety of organisms, including fungi and mycobacteria, may be responsible, gram negatives, most commonly E. coli, account for most cases.

Effective treatment of the infection and recovery of renal function depend on prompt relief of obstruction. This may be accomplished percutaneously by nephrostomy placement or internally by ureteral stent placement. Loss of renal function is variable although directly related to the duration of obstruction. Nonetheless, following adequate antibiotic treatment and drainage, recovery of renal function may occur despite prolonged periods of obstruction.

Pyohydronephrosis can and commonly does coexist with pyelonephritis or abscess. Patients typically present with acute flank pain and signs and symptoms of infection. Presentation, however, may be subacute. A small but significant number of patients, approximately 15%, are asymptomatic; pyohydronephrosis is discovered only when grossly purulent material is found during nephrostomy or other procedure for relief of hydronephrosis.

Computed tomography findings suggestive of pyohydronephrosis include increased thickness of the wall of the renal pelvis and the presence of increased density within the renal pelvis indicative of pus or debris. Perirenal fat stranding is often present, but it can also be present in cases of noninfected hydronephrosis. In pyohydronephrosis, these perinephric changes are often more severe.
The strongest indicator of pyohydronephrosis on CT is the presence of gas within the collecting system; however, this finding is only occasionally present. In most patients, CT findings alone cannot reliably distinguish between an infected and an uninfected hydronephrotic kidney. Nonetheless, the usefulness of CT in the setting of pyohydronephrosis should not be underestimated. CT can identify the source of the urinary obstruction. CT can also evaluate intrarenal and extrarenal extension of disease, such as concurrent pyelonephritis or abscess formation, which may or may not require separate drainage.

Sonography may identify echogenic contents within a dilated renal collecting system. Occasionally, debris may be seen to layer dependently within the dilated renal pelvis. Although such an appearance may be present on the basis of hemorrhage or other conditions, in the appropriate clinical setting the finding of increased echogenicity or debris within the renal pelvis is strongly indicative of pyohydronephrosis. Nearly half of patients with pyohydronephrosis, however, may have a dilated collecting system without significant internal echoes, which are findings indistinguishable from an uninfected hydronephrotic collecting system.

**Emphysematous Infection**

Gas-forming pathogens within the urinary tract include *E. coli, Klebsiella pneumoniae, Aerobacter aerogenes, Proteus mirabilis,* and *Candida tropicalis.* Infection by gas-forming organisms may result in gas collections seen within the renal parenchyma, within an obstructed renal collecting system, or within a localized abscess cavity. The location of the gas has important implications for prognosis and treatment.

Gas-forming infection within the renal parenchyma is termed *emphysematous*
Emphysematous pyelonephritis. Emphysematous pyelonephritis represents an unusual, fulminant, necrotizing, life-threatening variant of acute pyelonephritis. Ninety percent of patients with emphysematous pyelonephritis are diabetic.\textsuperscript{17} Emphysematous pyelonephritis may be seen with or without urinary obstruction; most nondiabetic patients have coexistent obstruction, and most diabetic patients do not.\textsuperscript{17} The classic treatment is emergent nephrectomy; however, with nonsurgical candidates, or where nephrectomy would lead to renal failure, nonoperative management with CT-guided drainage may be attempted.

Gas may be seen on plain radiographs (Fig. 11), although it may be mistaken for bowel gas. Because of the large difference in radiograph attenuation between gas and soft tissue, CT is exquisitely sensitive in the detection of gas. Parenchymal gas typically appears as multiple small bubbles or as linear streaks radiating from the papillae as the gas dissect along the planes of the renal interstitium. In emphysematous pyelonephritis, gas may often be present in a subcapsular location, forming a sharp line around the outer margin of the kidney. Gas may also be seen extending into the retroperitoneum.

In emphysematous pyelonephritis, gas may often be seen within the renal collecting system. The presence of air seen only within the collecting system and not within the renal parenchyma, however, should not be confused with emphysematous pyelonephritis. The presence of gas within an infected, obstructed collecting system has been termed emphysematous pyonephrosis, emphysematous pyelitis, or, most simply, pyonephrosis with gas. This condition does not carry the same grave prognostic implications as emphysematous pyelonephritis. Treatment and outcome is similar to pyonephrosis without visible air. Patients with emphysematous pyonephrosis do not have the same overwhelmingly diabetic distribution as seen in emphysematous pyelonephritis.

Similarly, gas may be seen within a well-defined intrarenal abscess, just as gas may be present in any abscesses located anywhere in the body. Thus, gas

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\caption{Emphysematous pyelonephritis in an elderly diabetic woman. Gas is seen in a striated pattern within the renal parenchyma. In addition, gas is seen in a subcapsular location, sharply defining the smooth outer edge of the kidney (arrows) and has dissected along the surface of the right psoas muscle (curved arrows).}
\end{figure}
Within an abscess should not be confused with emphysematous pyelonephritis and does not carry the same implications of fulminant, necrotizing, life-threatening infection.

Whereas CT directly images gas, ultrasound identifies gas largely by the artifact that it creates. As discussed previously, gas may be recognized on sonography as a highly reflective area with a "dirty" gray shadow, as opposed to the black shadow seen with calcified structures such as renal calculi. The distinction, however, between types of shadows may not always be clear-cut. Moreover, extensive shadowing caused by gas may obscure large portions of the affected kidney, which can lead to difficulty in distinguishing the location of the gas. As discussed above, the location of the gas is extremely important. The unequivocal identification and localization of gas by CT and the superior visualization of the kidney and extrarenal tissues make CT the imaging modality of choice.

Renal Tuberculosis

Tuberculosis (TB) of the kidney is uncommon in the United States, occurring as a result of hematogenous spread following a primary infection in the lung. Mycobacteria reaching the kidney by way of the bloodstream form miliary foci of infection typically bilaterally within the renal cortex; the cortical location reflects the distribution of blood flow within the kidney. When cellular immune mechanisms are adequate, the infection is contained within small granulomas. These granulomas are not visible on imaging studies and may remain clinically silent for 5 to 25 years. Reactivation occurs as granulomas enlarge and rupture into the renal tubular system, infecting the medullary pyramids and forming tuberculomas.

The long lag time between initial lung infection and renal manifestations explains the fact that most patients with renal TB have chest radiographs that are either normal or show sequel of healed primary infection. Patients are often unaware of their initial pulmonary infection. Patients with renal TB are often asymptomatic or have mild, nonspecific complaints, such as dysuria, nocturia, frequency, or pain. To further complicate diagnosis, standard laboratory tests are unrevealing, with typical findings of hematuria or sterile pyuria. It is no wonder that the diagnosis may remain a mystery for long periods of time, presenting as urinary tract infection that persists or recurs despite repeated therapy for the usual pathogens.

Although both kidneys are typically involved with tuberculous infection, imaging studies frequently demonstrate unilateral abnormalities. Possible imaging findings are legion and reflect the many possible routes of development of the tuberculoma. The tuberculoma may enlarge and mimic a mass, may calcify, or may rupture into an adjacent calyx and form a cavity that communicates with the collecting system. Involvement of the collecting system leads to ulceration. Resulting fibrosis may lead to stricture formation or obstruction involving the infundibulum, pelvis, or ureter. An obstructed renal lobe or entire kidney may proceed to an end-stage with nonfunction and hydronephrosis or with atrophy and calcification.

Excretory urography (IVP) is the most sensitive imaging modality in the earlier stages. The earliest of all imaging findings is subtle irregularity of the calyceal contour resulting from mucosal edema as the inflammatory process involves a medullary pyramid. IVP or retrograde pyelography may demonstrate areas of cavitation that communicate with the collecting system or strictures that
are commonly multiple. It should be noted that because these strictures form as a result of the healing response (fibrosis), they may appear or progress during treatment. CT has some advantages over urography in that it is more sensitive to calcifications, can visualize nonfunctioning or obstructed renal lobes or entire kidneys, and can image extrarenal extension of disease.

**Xanthogranulomatous Pyelonephritis**

Xanthogranulomatous pyelonephritis (XGP) is an uncommon inflammatory process of the kidney, which results in focal or diffuse renal enlargement and nonexcretion from a portion of the kidney. Obstruction in the kidney is a typical part of XGP, and this is frequently caused by calculus disease, either a focal
stone or a staghorn calculus. There are two important features of XGP that should be remembered. First, this lesion can mimic neoplastic disease because it consists of a mass. Second, there is a tendency for XGP to spread; when it does spread beyond the kidney or beyond the perinephric space, there may not be an apparent attachment to the initial lesion, which can raise diagnostic confusion.

The pathologic hallmark of XGP is the "foam cell," which is a lipid-laden macrophage. Whereas on excretory urography the lesion presents as a nonfunctioning enlarged kidney or as a focally nonfunctional large portion of a kidney, on CT the lipid-laden macrophages give a relatively low density to the affected area. CT density numbers tend to be between $-15$ and $+10$ HU.

Computed tomography is the technique most commonly used today to identify and stage XGP. On CT, the compressed normal parenchyma outside of the centrally located lipid-laden macrophages is identified because of its contrast enhancement. Calculi are seen when present. Nephromegaly and thickening of Gerota's fascia are typical additional findings. Infiltration into the perinephric space and identification of inflammatory abnormalities in areas beyond the perinephric space, such as the psoas muscle (Fig. 13), are extremely helpful in diagnosis and in determining therapy.

Clinically, XGP may have nonspecific symptoms or may have ones that suggest infection, such as fever, chills, and malaise. Urinary tract symptoms such as nocturia, dysuria, frequency, and flank pain may be identified. The most common group to develop XGP is middle-aged women. Although the

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Figure 13. Xanthogranulomatous pyelonephritis involving the upper pole of a duplicated system. A, Transverse sonogram of the upper pole of the left kidney (K) demonstrates renal parenchyma of apparent normal thickness and echotexture (solid black arrows). A portion of a calculus is seen as a focal area of high-level echoes without definite acoustic shadowing (white arrow). The mass posterior to the kidney (open arrows) proved to be a psoas abscess. B, CT scan with intravenous contrast medium shows the left renal calculus (long black arrows). Low-density masses of xanthomatous tissue (m) have replaced the parenchyma adjacent to the renal sinus. These masses were not detected sonographically because they resembled normal renal parenchyma. The renal parenchyma is actually thinned (short black arrows). The inflammatory process extended into the left psoas muscle (large white arrow). (From Piccirillo M, Rigsby C, Rosenfield AT: Contemporary imaging of renal inflammatory diseases. Infect Dis Clin North Am 1:952, 1987.)
Figure 14. Xanthogranulomatous pyelonephritis. Plain film (A) shows extensive right-sided abdominal calcification, subsequently shown on CT scan (B) to represent nephrolithiasis. CT scan shows distended calyces with low-density material typical of XGP. Note spread of disease to posterior abdominal wall (arrows) with no apparent connection to diseased right kidney.
inflammatory process begins in the renal pelvis, it eventually extends to the parenchyma, first in the medulla and then the cortex.

Sonography may reveal some of the features of XGP such as nephrolithiasis and perinephric extension. Of interest, the foam cells are frequently isoechoic with normal renal parenchyma so that the lesion on sonography looks like normal parenchyma, whereas on CT there is only a very thin rim of parenchyma (Figs. 14 and 15). This discordance in size of the parenchyma of the kidney is highly suggestive of XGP.26

Modern imaging, particularly CT, is helpful in making the diagnosis of

Figure 15. Replacement lipomatosis represents an uncommon end-stage of long-standing inflammation, not to be confused with XGP. Like XGP, there is a strong association with renal calculi.1 With replacement lipomatosis, there is marked atrophy of renal parenchyma and replacement by fibroadipose tissue. A, Severe loss of parenchyma of left kidney with fat seen in its place. Note remnant of renal vein (arrow). B, Renal calculus (curved arrow) is still present.
XGP, a lesion that is frequently unsuspected because there may not even be a history of urinary tract infection. If a nonfunctioning kidney is seen with a calculus and there is evidence of spread to adjacent structures, these appearances are characteristic of XGP. A low CT number on noncontrast scans is also helpful. At times, the distinction between XGP and neoplastic disease is impossible. This is not necessarily a problem because XGP is staged by CT in a manner to renal cell carcinoma, and since the treatment for both lesions is nephrectomy. Any patient with features suggestive of XGP on an IVP should have a CT scan for further evaluation.

**SUMMARY**

Traditionally, imaging of renal infections was largely through a multimodality approach. Excretory urography, ultrasonography, nuclear scintigraphy, and CT all played major roles; however, in recent years, CT has increased in prominence in the imaging and evaluation of renal infection. Part of the reason for this trend includes improvements in the availability of CT scanners and more timely access to them. Helical scanning technology has also greatly increased the quality and usefulness of the information CT provides.

Most uncomplicated cases of acute renal infection in adults do not require imaging for diagnosis and treatment. When imaging is indicated, however, contrast-enhanced CT almost always is the study of choice. For cases in which renal calculi may be present, the study should also include noncontrast images through the kidneys.

**References**


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