Hematuria can be well evaluated with a comprehensive contrast material-enhanced multi-detector row computed tomography (CT) protocol that combines unenhanced, nephrographic-phase, and excretory-phase imaging. Unenhanced images are obtained from the kidneys to the bladder and allow optimal detection of renal calculi, a common cause of hematuria. Renal parenchymal abnormalities, particularly masses, are best visualized on nephrographic-phase images, which also provide excellent evaluation of the other abdominal organs. Thin-section delayed images obtained from the kidneys to the bladder demonstrate the urinary tract distended with contrast material and are useful in detecting urothelial disease. Intravenous urography, ultrasonography, CT, retrograde ureterography and pyelography, cystoscopy, and ureteroscopy can all be used to evaluate patients with hematuria. In the past, a combination of several of these examinations was necessary to fully evaluate these patients. Now, however, this CT protocol may permit evaluation of hematuria patients with a single comprehensive examination, although more experience and data are needed to determine its efficacy in this setting.

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Introduction
Many imaging modalities have been used in the evaluation of patients with hematuria. Historically, intravenous urography (IVU) has been the primary method of imaging in these patients (1,2). Currently, the examinations that are commonly used to evaluate patients with hematuria include IVU, ultrasonography (US), computed tomography (CT), magnetic resonance (MR) imaging, retrograde ureterography and pyelography, cystoscopy, and ureteroscopy (3).

Hematuria can have a wide range of causes, including calculi, neoplasms, infection, trauma, drug toxicity, coagulopathy, and varices (4). Occasionally, the cause is revealed by a clinical history of prolonged exercise or recent instrumentation.

Evaluation of patients with hematuria frequently requires several imaging modalities. Assessment for urologic malignancy is probably the most important reason for evaluating these patients; therefore, examinations with a high sensitivity for the detection of neoplasms are essential. The ability to detect other possible causes of hematuria is also important.

Unenhanced CT is routinely used to evaluate for calculi and hydronephrosis (5). Renal masses are usually characterized with CT, US, or MR imaging. Urothelial disease has traditionally been evaluated with IVU or retrograde ureterography and pyelography. Excretory-phase CT can now be used to evaluate the ureters (2,6). Although excretory-phase CT is a relatively new technique, preliminary results demonstrate a high sensitivity (95%) in detecting upper tract uroepithelial malignancy (7). Although CT may also demonstrate bladder disease, flat tumors of the bladder are unlikely to be identified with CT, and cystoscopy remains the study of choice in evaluating for bladder malignancy.

With the advent of spiral CT and particularly multi-detector row CT, it is possible to perform a comprehensive evaluation of hematuria patients with a single examination (8–10). CT urography can be performed with a combination of unenhanced, nephrographic-phase, and excretory-phase imaging. The unenhanced images are ideal for detecting calculi. Renal masses are detected and characterized with a combination of unenhanced and nephrographic-phase imaging. The excretory-phase images provide evaluation of the urothelium. Three-dimensional (3D) reformation of the excretory-phase images can produce images that mimic the appearance of intravenous urograms, thus providing images in a format that is familiar to many referring physicians. Alternatively, post-CT conventional radiography can provide similar information (11).

In this article, we review multi-detector row CT technique in patients with hematuria. We also discuss and illustrate a variety of entities that are frequently associated with hematuria, including calculi, renal masses, papillary and caliceal abnormalities, renal pelvic and ureteral disease, bladder disease, and congenital anomalies. In addition, we briefly discuss the role of other imaging modalities in the evaluation of hematuria patients.

Imaging Technique
Examinations were performed on a Lightspeed CT scanner (GE Medical Systems, Milwaukee, Wis). All imaging was performed with a 1.5:1 pitch, four detector rows, and a table speed of 15 mm per rotation. Typically, the examinations were performed at 120 kV and 340 mA with a rotation time of 0.8 seconds, although the milliampere was often adjusted depending on patient size. To facilitate 3D reformatting, orally administered contrast material was not used for this technique. Unenhanced images were obtained from the kidneys through the bladder. One hundred milliliters of iopromide (Ultravist 300; Schering AG, Berlin, Germany) was administered intravenously at a rate of 2 mL/sec, and nephro-
graphic-phase images of the abdominal organs were obtained. Following the injection of contrast material, a 250-mL bag of normal saline solution was administered rapidly by intravenous drip to distend the ureters. Excretory-phase images were obtained 8 minutes after contrast material administration (Table). Overlapping reconstruction of the excretory-phase data was performed and the resulting images sent to a Vitrea workstation (software: Vital Images version 2.6, Plymouth, Minn). At one of our sites, patients were also sent for a single abdominal radiograph (kidney, ureter, bladder) immediately after undergoing CT.

The unenhanced images were obtained to evaluate the urinary tract for calculi and to assist in the characterization of renal masses. An alternative technique, which we did not use, consists of obtaining unenhanced images of the kidneys only and nephrographic-phase images of the entire abdomen and pelvis. Occasionally, however, contrast material excretion can be seen on nephrographic-phase images and may obscure ureteral calculi. The additional benefit of dynamic imaging of the pelvis with this technique was thought to be small, and we elected not to use the technique.

Some investigators have included arterial-phase images through the kidneys and bladder to evaluate for vascular abnormalities (12). Arterial-phase images may be particularly helpful in detecting arteriovenous malformations and demonstrating the arterial anatomy in surgical candidates. Other vascular abnormalities such as aberrant renal veins and venous thrombosis can usually be seen on nephrographic-phase images. Others advocate the addition of corticomedullary-phase imaging of the abdomen for better characterization of renal masses and particularly for better evaluation of the liver (13,14). Although these additional imaging techniques may increase the diagnostic yield of the CT examination, the additional benefit is small and, in our opinion, routine use of corticomedullary-phase imaging is not justified because of the potential risks posed by the additional radiation dose (15).

Recently, a new technique has been described that can reduce the examination to two phases (16). With use of a dual contrast material bolus, nephrographic- and excretory-phase imaging can be performed concurrently, thus reducing radiation exposure and the number of images generated.

Three-dimensional reformation was performed with volume rendering (VR) or maximum-intensity-projection (MIP) techniques. Although both techniques demonstrate the urinary tract well, VR was preferred at our institution because it does not obscure superimposed structures such as the pelvic bones and ureters. However, caliceal detail was occasionally better seen on MIP images. The 3D reformation was performed by the radiologist and could usually be completed within 5 minutes.

One concern about this comprehensive CT technique is radiation dose to the patient. Each series of the examination delivers a dose of approximately 10 mGy (1 rad). This dose is significantly higher than the typical dose for IVU. To limit the dose, we decided not to cover the entire abdomen and pelvis on all phases of the examination and to limit the examination to three phases.

Calculi
Renal, ureteral, and bladder calculi are a common cause of hematuria. Twelve percent of people develop kidney stones at some point during their lifetime (17). The best imaging modality for evaluating calculi is unenhanced helical CT, which is commonly performed in patients with renal colic to detect obstructing calculi (18–20). In patients with hematuria, unenhanced CT is also helpful in detecting nonobstructing calculi. Although conventional radiography may help detect urinary calculi, it is not as sensitive as unenhanced CT (5). US is also useful in detecting renal calculi and may demonstrate hydronephrosis due to obstructing ureteral calculi but often does not allow direct visualization of ureteral calculi (21,22). The unenhanced portion of our CT examination provides optimal evaluation of all urinary calculi as well as evaluation for hydronephrosis related to the calculi.

Renal Masses
Renal masses frequently manifest with hematuria. Characterization of a renal mass as a simple cyst, a complex cyst, or a solid mass is essential. Simple cysts are benign and do not warrant further evaluation. Solid masses, with the exception of angiomylipomas, are presumed to be malignant and usually require surgery.
Features of complex cysts that must be evaluated include wall thickness, presence and thickness of septa, calcifications, attenuation of the cyst, and foci of enhancement. Cystic renal masses are often characterized according to the Bosniak classification system (23–25). Category I lesions are simple cysts. Category II lesions are slightly more complicated and may contain a few thin septa, thin calcifications, or high-attenuation fluid. Category III lesions are still more complex and may contain foci of wall or septal thickening. Category IV lesions have solid enhancing areas. As a general rule, category I and II lesions are benign, whereas category III and IV lesions are possibly malignant and warrant surgery. In cystic masses that are difficult to differentiate as category II or category III lesions and in cysts with thick calcifications, category IIF may be used, and these lesions warrant close follow-up (26). In

**Figure 1.** Bosniak category II renal cyst in a 47-year-old man. (a) Axial unenhanced CT scan demonstrates a large cyst with an attenuation value of 23 HU at the upper pole of the left kidney. (b) On an axial nephrographic-phase CT scan, the cyst has an attenuation value of 25 HU, indicating no significant enhancement.

**Figure 2.** Renal cell carcinoma in a 52-year-old woman. (a) Axial nephrographic-phase CT scan demonstrates a heterogeneous mass with central necrosis at the upper pole of the right kidney (arrows). (b) Coronal excretory-phase MIP image demonstrates the relationship of the mass (arrows) to the collecting system.
addition, small renal masses may be difficult to characterize because of lack of accurate evaluation of enhancement characteristics due to volume averaging or pseudoenhancement (27).

CT, US, and MR imaging are all excellent for differentiating renal cysts from neoplasms. CT characterization of a renal mass depends on a combination of unenhanced and contrast material–enhanced imaging. The best phase for contrast-enhanced imaging is the nephrographic phase, which is performed slightly later than the typical corticomedullary-phase imaging commonly used for the abdomen (28–30). These imaging sequences permit characterization of masses as simple cysts, complex cysts, or solid neoplasms (Figs 1, 2). Although US is also excellent for differentiating cystic from solid renal masses, it is less sensitive in detecting solid masses that may be isoechoic relative to normal renal parenchyma.

MR imaging is also excellent for characterizing renal masses, although it does not clearly demonstrate calcification in these masses. IVU is much less sensitive in detecting renal masses and is not reliable for differentiating cystic from solid renal masses. Because our protocol includes both unenhanced and nephrographic-phase imaging, it provides excellent evaluation of all types of renal masses.

**Papillary and Caliceal Abnormalities**

Papillary necrosis can have a wide range of causes, including diabetes, analgesic abuse, sickle cell disease, pyelonephritis, renal vein thrombosis, and obstructive uropathy. Traditionally, papillary necrosis has been diagnosed primarily with IVU. In papillary necrosis, contrast material in the collecting system fills a necrotic cavity that may be located centrally within or at the periphery of the papilla. Excretory-phase CT may provide similar visualization of the collecting system, allowing the diagnosis of papillary necrosis to be made, although its sensitivity in detecting this pathologic condition has not been determined (Fig 3).

Like papillary necrosis, pelvocaliceal diverticula may manifest as contrast material–filled fluid adjacent to the calices, but these two entities can usually be distinguished on the basis of the location of the fluid collections. Pelvocaliceal
Figure 4. Caliceal diverticulum with calculi in a 64-year-old man. (a, b) Axial unenhanced (a) and nephrographic-phase (b) CT scans demonstrate calculi (arrowhead) layering in a fluid collection (black arrow in b) at the lower pole of the left kidney. An inferior vena cava filter (white arrow) is incidentally noted. (c, d) Axial excretory-phase CT scans demonstrate contrast material excretion into a portion of the fluid collection (arrow), a finding that represents a caliceal diverticulum. An unenhanced fluid-attenuation mass representing a cyst is seen adjacent to the diverticulum (arrowhead in d). (e) Excretory-phase MIP image demonstrates the caliceal diverticulum (arrow).
Diverticula are not located in the papilla but adjacent to the fornices of the calices or, less commonly, adjacent to an infundibulum or the renal pelvis (Fig 4).

Patients with medullary sponge kidney are often asymptomatic but may present with hematuria, infection, or renal colic. These patients have dilatation of the collecting tubules, which typically have a “paintbrush” appearance at IVU. In addition, affected patients frequently have small calculi. Unenhanced CT may demonstrate these small calculi, and the paintbrush appearance can be seen at excretory-phase CT (Fig 5).

Nephrocalcinosis is characterized by medullary calcifications and is most commonly seen in patients with hyperparathyroidism, renal tubular acidosis, and medullary sponge kidney. These calcifications are best visualized at unenhanced CT, which is more sensitive than radiography in this setting (Fig 6).

Figure 5. Medullary sponge kidney and an obstructing calculus in the right distal ureter in a 62-year-old woman. (a) Axial unenhanced CT scan demonstrates right hydronephrosis (arrowheads) with a nonobstructing calculus (arrow). (b) Axial unenhanced CT scan demonstrates a calculus in the distal right ureter (arrow). (c, d) Axial excretory-phase CT scan (c) and post-CT radiograph (d) demonstrate a paintbrush appearance in the papillae of the left kidney (arrows). Right hydronephrosis is again noted (arrowheads in c).
Figure 6. Nephrocalcinosis in a 33-year-old woman. Axial unenhanced (a) and excretory-phase (b) CT scans demonstrate medullary calcifications bilaterally (arrowheads). Left hydronephrosis is also noted (arrow in b). The calcifications were not visible at abdominal radiography.

Figure 8. UPJ obstruction and nonobstructing calculi in a 35-year-old man. (a, b) Axial unenhanced (a) and excretory-phase (b) CT scans demonstrate right hydronephrosis with thickening of the urothelium in the renal pelvis (arrowheads). Note the calculi layering in the collecting system (arrows in a). (c) Three-dimensional VR image of the collecting systems demonstrates right hydronephrosis due to UPJ obstruction. Note that the left renal collecting system is incompletely distended.
Renal Pelvic and Ureteral Disease

A filling defect in the renal pelvis or ureter can be due to a neoplasm, calculus, blood clot, mycetoma, or vascular impression (Fig 7). Obstruction at the ureteropelvic junction (UPJ) may occur due to a short segment of nonfunctional smooth muscle and typically manifests with hydronephrosis (Fig 8). Other types of ureteral abnormalities include narrowing due to stricture or extrinsic disease. Complications of ureteroscopy may also occur (Fig 9).

Figure 7. Transitional cell carcinoma of the left ureter with associated left hydronephrosis in a 77-year-old woman. (a) Axial nephrographic-phase CT scan demonstrates left hydronephrosis (arrowheads) with associated delayed medullary enhancement (arrows). (b) Axial nephrographic-phase CT scan demonstrates left hydroureter (arrowheads). (c) Axial nephrographic-phase CT scan obtained several centimeters below b demonstrates an enhancing mass in the ureter (arrow). (d) Coronal excretory-phase reformatted image demonstrates left hydronephrosis and hydroureter (arrowheads) with an obstructing soft-tissue mass in the ureter (arrow).
Traditionally, ureteral disease has been evaluated with IVU or retrograde ureterography. However, these examinations only demonstrate the lumen of the ureter and do not allow direct visualization of extrinsic abnormalities that involve the ureter. In the case of a vascular impression, in addition to demonstrating the impression on the collecting system, CT may directly demonstrate the vessel that is causing the impression (Fig 10). If a crossing vessel is suspected of causing an extrinsic impression on the ureter or UPJ obstruction, the addition of arterial-phase images should be considered for better visualization.

Excretory-phase CT allows visualization of both the ureteral lumen and periureteral abnormalities; however, it is a new technique, and only preliminary data are available concerning its sensitivity in detecting small urothelial neoplasms (7). Accurate evaluation of excretory-phase images requires a wide window setting (eg, bone windows). The 3D reformatted images depict the collecting system and ureters in a format that is familiar to most referring clinicians. In our experience, renal pelvic and ureteral disease is best evaluated and almost always appreciated on the axial source images, but in rare instances we have detected ureteral disease on the 3D reformatted images that was not identified at initial review. In
one case, for example, we failed to detect mild hydronephrosis on the axial source images but identified it on the 3D reformatted images, even though in retrospect the hydronephrosis was also depicted on the axial source images. A potential problem with excretory-phase CT is that the ureters are imaged only once during this phase, whereas IVU may be used to obtain either one or multiple images of the ureters depending on the protocol of the institution. Therefore, if segments of the ureters are not filled with contrast material at a given moment, they may not be completely evaluated. Intravenous or oral hydration of patients can be used to distend the ureters with contrast material and has been shown to significantly improve ureteral opacification (31,32). Others have used compression technique to achieve better distention and evaluation of the collecting systems (32,33). Even in cases of incomplete opacification of the ureters, the un-opacified portions can often be followed and evaluated on the axial images.

**Bladder Disease**

Bladder abnormalities are a common cause of hematuria and include neoplasms, usually transitional cell carcinoma, particularly in patients with exposure to aniline dyes, phenacetin, tobacco,

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**Figure 10.** Vascular impression on the left renal pelvis in a 25-year-old woman. (a) Intravenous urogram demonstrates a nonspecific filling defect in the left renal pelvis (arrows). (b) Three-dimensional VR image (posterior projection) demonstrates the filling defect (arrows). (c, d) Sagittal reformatted image (c) and axial excretory-phase CT scan (d) demonstrate an extrinsic impression on the posterior aspect of the renal pelvis (arrows). (e) Axial nephrographic-phase CT scan demonstrates a branch of the left renal vein (arrowheads) that is causing the extrinsic impression on the renal pelvis.
and prior radiation therapy (Fig 11). Squamous cell carcinoma and adenocarcinoma are less common bladder neoplasms. Cystitis and diverticula are other types of bladder disease that may also cause hematuria. Bladder diverticula may be congenital, such as Hutch and urachal diverticula, or they may be acquired. Diverticula can predispose to carcinoma, calculi, or infections (Fig 12).

Many imaging modalities including CT, US, cystography, IVU, and MR imaging can be used to evaluate the bladder. Bladder distention is essential for optimal CT evaluation. Urine, contrast material excreted by the kidneys, and contrast material or air instilled directly into the bladder (CT cystography) all provide adequate contrast to visualize bladder disease at CT. However, flat tumors of the bladder may go undetected. Therefore, cystoscopy remains the standard for evaluation of the bladder for neoplasms and may be a necessary additional study in patients suspected of having bladder carcinoma.
Congenital Anomalies

Some congenital anomalies of the urinary tract are associated with hematuria, such as polycystic kidney disease. During the work-up of patients with hematuria, anomalies may also be detected incidentally. Congenital renal and ureteral anomalies include anomalies of position, form, number, or function. Most renal anomalies are well demonstrated with CT, US, IVU, and MR imaging (Fig 13). Ureteral anomalies are best demonstrated by filling the ureters with contrast material, with either IVU or excretory-phase CT (Figs 14, 15).

**Figure 14.** Duplication of the left renal collecting system and ureter in a 48-year-old man. (a) Axial excretory-phase CT scan demonstrates two left ureters (arrowheads). (b) Excretory-phase VR image demonstrates duplication of the left renal collecting system (arrows) and ureters (arrowheads).

**Figure 15.** Ureterocele in a 31-year-old woman. The left kidney had been removed many years earlier due to an unknown “benign cause.” (a) Axial excretory-phase CT scan demonstrates right hydronephrosis (arrows). (b) Axial excretory-phase CT scan demonstrates a dilated ureter (arrowhead) terminating in a ureterocele (arrows). (c) Excretory-phase VR image demonstrates hydronephrosis (black arrows), hydroureter (arrowhead), and the ureterocele (white arrow).
Roles of Other Imaging Modalities

In the evaluation of patients with hematuria, IVU and cystoscopy have been the primary methods of evaluation, along with a cross-sectional examination of the kidneys. Cystoscopy is still an essential part of this evaluation because radiologic examinations are not as sensitive in the detection of small bladder neoplasms, particularly superficial tumors. Although the results of CT urography are still preliminary, IVU will probably play only a small role in this work-up, particularly with the advent of new CT technology (eg, 16-detector CT), which will improve z-axis resolution.

US is less sensitive than CT in the detection of small solid renal masses and calculi and should not be the primary examination in patients with hematuria. However, US may still be helpful in characterizing cystic renal masses that are indeterminate at CT and in patients in whom intravenous contrast material is contraindicated.

MR imaging should be used to study the kidneys and ureters in such patients because it provides excellent evaluation of the renal parenchyma for masses, and MR urography can be used to evaluate the ureters (34). However, MR imaging is not sensitive in detection of urinary calculi, and its spatial resolution is inferior to that of CT.

Conclusions

Many different imaging modalities have been used in the evaluation of patients with hematuria, and patients frequently require multiple examinations for work-up. Contrast-enhanced multi-detector row CT urography performed with a combination of unenhanced, nephrographic-phase, and excretory-phase imaging can demonstrate a wide spectrum of disease in these patients with a single study. Unenhanced imaging provides optimal detection of calculi, a common cause of hematuria. In addition, the combination of unenhanced and nephrographic-phase imaging provides outstanding evaluation of renal masses. Findings at excretory-phase imaging mimic IVU findings and allow excellent evaluation of the collecting systems and ureters. Bladder disease, a common cause of hematuria, is often well seen on unenhanced or excretory-phase images, although cystoscopy may still be necessary. Although more experience and data are necessary, this protocol has the potential to provide accurate evaluation of patients with hematuria with a single comprehensive CT examination.

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