Urolithiasis is a universal problem, affecting patients across geographical, cultural, and racial groups. The incidence of urinary stones has shown a progressive increase in industrialized nations, and a similar trend is now being observed in developing countries due to changing social and economic conditions. The lifetime risk of nephrolithiasis ranges from 10 to 25%, with a high rate of relapse of 50% in five to 10 years and 75% in 20 years. It is estimated that over 5% of the US population are diagnosed with nephrolithiasis in their lifetime. The rising prevalence of urolithiasis in the US has risen from an estimated $1.83 billion in 1993 to $3,500 per person in 2000, and the annual healthcare burden of treating urolithiasis in the US has risen from an estimated $1.83 billion in 1993 to $5.3 billion in 2000.

Concurrent to the increasing incidence is the growing utilization of imaging for the diagnosis, treatment planning, and follow-up of patients with calculi disease. Imaging has evolved over the years due to technological advances and better understanding of the disease process. Conventional techniques such as radiography and excretory urography have been superseded by computed tomography (CT) since the late 1990s. The emergence of multidetector CT (MDCT) in 1998 and the recent introduction of dual-source CT (DSCT) have heralded a new era in the diagnosis of urolithiasis, with a promising future. The scope of imaging has extended beyond the mere detection of a stone and its location to determination of its composition, fragility, and quantification, which has great implications in treatment planning. In the emergency department, unenhanced CT performed for clinical suspicion of urolithiasis accounts for nearly 22% of the CT examinations undertaken for evaluation of acute abdominal pain. Furthermore, determination of ureterolithiasis by imaging alters management in nearly 60% of patients believed to have acute renal colic based on history, physical examination, and laboratory studies.

Types of Stone
A wide range of familial, environmental, dietary, and systemic factors contribute to the pathogenesis of renal stones. Stones are composed of a combination of crystals (inorganic and organic) and proteins. The most commonly encountered stones are calcium-based, and account for 70–80% of urinary stones. Calcium-based stones include calcium oxalate monohydrate (COM), calcium oxalate dehydrate (COD), and calcium phosphate stones. Struvite stones, which account for 5–15% of stones, are composed of magnesium ammonium phosphate and are usually seen in the presence of chronic urinary tract infection (UTI) with urea-splitting organisms such as Proteus spp. and Klebsiella spp. Urinary stones account for 5–10% of stones. Other stones, such as cystine stones, xanthine stones, protein matrix stones, and stones composed of drugs such as indinavir and trimethamere, are rare and account for fewer than 5% of stones.

The Urologist’s Perspective and Treatment Options
The three most important factors influencing decisions for urological intervention are stone size, stone composition, and the patient’s symptoms. A stone <5mm with well-controlled pain has a greater than 80% chance of passing spontaneously (see Figure 1). Medical expulsive therapy consisting of hydration and alpha blockers such as tamsulosin has been used to treat ureteral stones <10mm, with reported increase in spontaneous stone passage. Medical expulsive therapy is also particularly useful in patients with uric acid stones with associated metabolic abnormalities.

Stones measuring ≥6mm or those causing considerable distress not well controlled with oral pain medication may require intervention with shock-wave lithotripsy (SWL) or endoscopic stone fragmentation, and necessitate removal. Percutaneous nephrolithotomy combined with SWL...
or open surgeries are most suitable for the treatment of very large stones (>2cm) or staghorn calculi. Also, as the stone gets harder and the patient gets larger, endoscopy is usually better suited than SWL.¹⁰ SWL is preferred in patients with proximal ureteric stones, while ureteroscopy is preferred with distal stones. Stone density, body habitus, and patient medical conditions often influence these recommendations.¹⁰

**Imaging Strategies for Urinary Stone Disease**

Plain abdominal radiography (KUB) has a limited role today in the initial diagnosis of patients with urinary stones due to factors—including bowel gas, extrarenal calcification, and patient habitus—that diminish its sensitivity in the detection of urinary stones. However, KUB is still favored in the planning of fluoroscopically guided SWL and monitoring the progress of stone fragments after SWL, especially in radio-opaque ureteric calculi. Intravenous urography fails to detect urinary calculi in 31–48% of cases and has the risks associated with injection of iodinated contrast. Although easily available and cost-effective, ultrasound has limited diagnostic value in the assessment of patients with suspected renal stones even when performed by an experienced radiologist, particularly in evaluation of distal ureteral calculi.¹¹ ¹²

**Computed Tomography**

Unenhanced helical CT has gained widespread acceptance as the initial investigation of choice for the evaluation of patients with suspected urinary tract calculi.¹³ ¹⁴ Since the first description of its utility by Smith et al. in 1995, unenhanced CT has been found to have a high degree of sensitivity (95–98%) and specificity (96–100%) in the diagnosis of urolithiasis.¹⁵ ¹⁶ The CT examination can be rapidly performed and does not require the administration of oral or intravenous contrast material.¹⁷ ¹⁸ The shorter examination time, greater sensitivity of CT for detection of stones, and increased detection of extrarrenal abnormalities are some of the advantages of CT over other imaging techniques.¹² CT helps to detect and diagnose extrarrenal abnormalities such as appendicitis, diverticulitis, pancreatitis, and gynecological lesions that might mimic ureteric colic by causing flank pain. An additional benefit is its ability to reveal urinary abnormalities such as congenital abnormalities, infections, and neoplasms whose diagnosis carries a greater clinical relevance than stone disease.¹⁹ Intravenous contrast administration is not routinely required during the CT evaluation of urinary calculi. However, contrast administration may be necessitated for differentiating distal ureteric stones from phlebolith or vascular calcification.¹³ Other situations—such as incidental detection of a tumor or other pathologies on an unenhanced scan—may demand contrast-enhanced CT (CE-CT). Spencer et al. suggested that CE-CT may also be essential in conditions such as ureteral strictures, duplicated system, or ureteropelvic junction, which have the potential to complicate a calculus procedure or decrease spontaneous calculus passage.¹²

**Multidetector Computed Tomography in Urolithiasis**

The utility of CT in the evaluation of urolithiasis is not only limited to the characterization of stones in terms of size, number, location, and identification of obstructive features. The near isotropic resolution of MDCT allows assessment of stone volume and quantification of stone burden, which benefits the urologist in surgical planning. The coronal reformations obtained from axial images allow rapid and accurate detection of calculi. CT also helps in the assessment of stone fragility and determination of stone composition by attenuation (Hounsfield unit [HU]) measurement. The determination of stone composition is now easily performed with the introduction of DSCT, an exciting new CT innovation with capabilities of tissue material differentiation.

**Value of Coronal Reformatted Images**

Axial image data sets are frequently used in the detection of renal stones. High-resolution coronal reformations generated automatically from isotropic data sets of 64-slice MDCT allow the rapid and accurate detection of urinary stones compared with that provided by axial images alone (see Figure 2). Since the urethral system is coronally oriented, detection of urinary stones would be better on coronal reformatted images. Coronal reformatted images read in conjunction with axial images have been found to facilitate the differentiation of phleboliths, calcified vascular plaques, or renal parenchymal calcification from urinary stones. Coronal reformations in particular improve detection of urinary stones that are unrecognized on axial images and enhance radiologist confidence. This technique is recommended as an ideal approach to MDCT interpretation for diagnosing...
Genito-urinary Imaging

Figure 3: Unenhanced Multidetector Computed Tomography Images in a 47-year-old Man with Acute Right Flank Pain

A: Coronal reformatted image clearly shows right ureteral stone with proximal ureteral dilatation (thin arrow). Mild renal enlargement and perirenal stranding are also seen (thick arrow). B: Axial image shows ureteral dilatation with perirenal edema and stranding (arrow). The patient was treated with shock-wave lithotripsy.

Figure 4: Flow Diagram Depicting Treatment Decisions Based on Stone Composition

CT = computed tomography; ESWL = extracorporeal shock-wave lithotripsy; HU = Hounsfield unit; PCNL = percutaneous nephrolithotomy.

Urinary stone disease, and benefits practicing urologists who are accustomed to visualizing the urinary tract in the coronal view.

Multidetector Computed Tomography Signs of Urolithiasis

Virtually all stones are visible on unenhanced CT, including those that are radiolucent on plain radiographs, such as uric acid, xanthine, or cystine stones.22 These stones have a greater attenuation value (>200 HU) than the surrounding soft tissue, and MDCT helps in accurate localization of the stone within the renal pelvicalyceal system or the ureter. The only stones that are difficult to visualize on CT include pure matrix stones and stones made of pure indinavir (a protease inhibitor used in the treatment of HIV).22 These stones are of soft-tissue attenuation (15–30 HU) and hence are likely to be missed on unenhanced CT. However, the presence of associated obstructive features and their clear visualization as filling defects in the contrast-filled pelvicalyceal system on the delayed phase of contrast administration help in their detection.

The most direct CT sign for ureterolithiasis is the visualization of a stone within the lumen of the ureter with proximal ureteral dilatation and distal normal caliber (see Figure 3).24 The diagnosis of ureterolithiasis can be confirmed by the demonstration of several secondary signs on CT.12,13 The most reliable signs include hydroureters, hydronephrosis, perinephric stranding, perirenal edema, and unilateral renal enlargement.13,14 Perinephric fat stranding and intrarenal collecting system dilatation have a positive predictive value (PPV) of 98% and a negative predictive value (NPV) of 91% for the detection of ureteric calculi.13 Less reliable findings are unilateral absence of white renal pyramid, thickening of the lateroconal fascia, and perinephric edema.13,14 Differences in renal parenchymal attenuation between obstructed and non-obstructed kidneys have also been used as a secondary sign of obstruction. The presence of these secondary signs on CT has urological implications. Large stones (>6 mm) in the proximal ureter with more than five secondary signs of obstruction are more likely to necessitate intervention such as endoscopic removal or lithotripsy.13

Multidetector Computed Tomography and Stone Burden

Stone size and burden evaluation by CT is the most important factor dictating treatment strategies and management in patients with urolithiasis. Stone size measurement obtained on CT is used to plan treatment and also accurately predicts the rate of spontaneous passage of ureteral stones.21 A stone ≤4 mm is more likely to pass spontaneously, with a stone passage rate of up to almost 98%.22,26 Accurate measurement of stone size is paramount as it helps to determine whether a patient is a candidate for medical expulsive therapy or for urological intervention. The greatest dimension of the stone is measured on CT with the reading obtained to the closest millimeter. An ideal method for stone measurement on CT is to measure the stone using electronic calipers on bone window settings (window width 1,120 HU and window level 300 HU) and with magnification x5.

Linear measurement methods commonly used with either spiral CT or radiography pose a problem in the quantification of irregularly contoured stones such as stag horn calculi. Measuring the stone volume would eliminate the problem associated with linear measurements. It is more appropriate to use total volume of the stones as a measurement of stone burden, and spiral CT has been found to provide accurate direct volume measurements of urinary calculi to a mean error of 5%.25

Multidetector Computed Tomography and Stone Composition

One of the key determinants of the appropriate management of a patient with urinary calculi is knowledge of the stone composition (see Figure 4). Determination of the stone composition enables a urologist to guide treatment planning such as urinary alkalisation and medical management in patients with uric acid stones as opposed to interventional procedures such as extracorporeal shock-wave lithotripsy (ESWL), ureteroscopy, or percutaneous lithotripsy in non-uric acid stones.26 The stone composition also affects the efficacy of ESWL. Brushite, cystine, and calcium oxalate monohydrate stones are hard and resistant to fragmentation by ESWL, while struvite stones usually fragment easily with ESWL, but struvite stones usually fragment easily with ESWL.21,26 Different tools are routinely used to infer stone composition including urine pH, urinary crystals, prior stone history, presence of urea-splitting organisms, and plain radiography.26,27 There has been a rise in the utility of CT for the assessment of stone composition.28,29,30 Determination of stone composition can be accomplished on CT using HU values of stones and with the help of DSCT.
Stone Composition Using Attenuation Measurements

Bellin et al. reported that helical CT attenuation and density assessment can be used to predict stone composition in vitro with 64–81% accuracy.30 Uric acid, cystine, COM, and brushite calculi have been identified with an accuracy exceeding 85% in vitro.31–33 Although there is variability in the attenuation measurements of different types of stone in various studies, particularly for struvite stones, CT is fairly accurate in predicting stone composition.31,33,34 The attenuation values of the various urinary calculi at 120kV are usually in the following range: uric acid 200–450HU, struvite 600–900HU, cystine 600–1,100HU, calcium phosphate 1,200–1,600HU, and COM and brushite 1,700–2,800HU. The differentiation of the various stones is more complicated and less reliable in vivo. Among other factors, it is also dependent on the accurate placement and size of the region of interest (ROI). Furthermore, use of HU measurements becomes more complicated in the presence of stones with mixed composition. Due to the lack of well-established criteria for differentiation of various stones on HU values and due to inconsistent results, the HU method of determining stone composition has not found widespread acceptance in routine clinical use.

Stone Composition Using Dual-energy Computed Tomography

DSCT, a recent innovation in CT technology, helps to differentiate urinary stones based on their composition in a more robust manner. Although initially developed for its cardiac applications, it has opened up new opportunities for imaging in the abdomen. DSCT is a 64-slice CT system equipped with two X-ray tubes and two corresponding 64-slice detector arrays mounted onto a gantry with an angle of 90º.39 DSCT allows concurrent scanning of two different energies (80 and 140kVp), and the resulting CT data can be exploited for tissue material characterization.40 Uric acid stones are composed of only light chemical elements (H, C, N, O) and their X-ray attenuation properties at high and low kVp are very different compared with other stone types (e.g. calcium oxalate, calcium hydroxyapatite, cystine, struvite) whose composition includes heavy elements (P, Ca, S).40–42 The dual-energy post-processing software algorithm assumes a mixture of water, calcium, and uric acid for every voxel, and color-codes voxels that show dual-energy behavior similar to calcium in blue and those similar to uric acid in red (see Figures 5 and 6). Voxels that show linear behavior at both tubes potential remain gray. Using dual-energy CT, differentiation of pure uric acid, mixed uric acid, and calcified stones is possible.40–42 It is also possible to differentiate struvite and cystine stones by modifications in the slope of three material decomposition algorithms.40–42 It has been demonstrated in a realistic phantom model that a dual-energy stone characterization technique can discriminate uric acid stones from other stone types with 92–100% accuracy depending on stone size and patient attenuation.42 The dual-energy scanning for renal stones involves an initial standard non-contrast low-dose MDCT scan of the entire abdomen and pelvis using a single-source technique. Once a stone has been localized, a localized focal dual-energy acquisition (140/80kVp) of the anatomical region containing the stone is performed. This is performed to substantially decrease radiation exposure.

Stone Frailty

Pre-treatment knowledge of the fragility of a stone is of great utility in planning an intervention, and allows the clinician to be more selective in choice of therapy. Some authors suggest that stone morphology rather than X-ray attenuation correlates with fragility of stones to SWL, and stone fragility can be predicted using pre-treatment CT.43,44 Studies have shown that COM and cystine stones that are heterogeneous on CT are more fragile than those that appear homogenous in structure and require less comminution.43

Potential Pitfalls/Stone Mimics

Extraurinary abdominal and pelvic calcifications such as phleboliths located in the expected course of the ureter on the symptomatic side may be confused with a ureteral calculus. Volumetric CT acquisition and routine use of coronal reformatations, which allow tracing of ureters, usually permit confident differentiation between calculi and other calcific processes. However, two signs—‘soft-tissue rim sign’ and ‘comet tail sign’—have been described for differentiation of the ureteral stones from these calcifications.19,20 Another helpful feature in terms of differentiation is the central lucency seen in phleboliths, in contrast to the dense centers seen...
Genito-urinary Imaging

Figure 7: Follow-up Computed Tomography Scans in a 55-year-old Man with Right Mid-pole Renal Calculus

A: Axial unenhanced computed tomography (CT) scan shows a right mid-pole renal calculus (arrow) (120kVp, 240mAs). B: Follow-up CT scan was performed with reduced technique (100kVp, 100mAs). Confident diagnosis of the renal calculus (arrow) can be made on the low-dose CT despite increased noise in the image.

Figure 8: Radiation Dose Reduction Strategies for Multidetector Computed Tomography in Urolithiasis

- Limit scanning area
- Use axial slices of 3–5mm thickness with thin coronal reformations
- Increase the noise index (20–35%)
- Reduction in kVp (80–100kVp)
- Reduction in mAs (50–100mAs)

Radiation Dose

A key concern in the imaging of urolithiasis with unenhanced helical CT is the increased radiation dose. This is especially a concern in young, healthy individuals who undergo repeated CT examinations due to recurrent stone disease, who are at high lifetime exposure risk. The effective radiation dose reported during unenhanced CT ranges from 2.8 to 13.1mSv for men and from 4.5 to 18mSv for women, which is higher than excretory urography (1.5mSv for three-film and 2.1mSv for six-film excretory urography). Several modifications can be made to the routine technique to achieve considerable reduction in the radiation dose exposure. A number of technological developments have taken place for radiation dose reduction in CT, including pre-patient collimation of X-ray beams, use of better image-processing algorithms, noise reduction filters, and efficient detector configuration.

A simple approach advocated by some authors for dose reduction in CT for urolithiasis is to use the low-dose techniques with very low tube current (50–100mAs), which has radiation dose benefits of up to 80% compared to standard scanning protocols (see Figure 7). Accuracy of 93–97% has been achieved in the detection of urinary calculi using these low-dose techniques. However, the fixed tube current technique is not suitable for patients of varying sizes. Automatic tube current modulation (ATCM) is a promising technique that allows optimization of radiation dose in MDCT based on patient size. As the name signifies, this technique adjusts the tube current according to the patient’s size while maintaining image quality and increasing dose efficiency. ATCM results in up to a 56% reduction in radiation dose in patients undergoing CT of the abdomen and pelvis. Further dose reduction while operating on ATCM can be achieved by increasing the noise level (index) of the images. A noise index of 12–15 is routinely used in the CT examinations of the abdomen and the pelvis. Increasing the noise index up to 20–35 significantly reduces the radiation dose exposure by 40–70%. In the authors’ practice, a noise index of 20 is used for the initial CT examination for evaluation of stone disease. Subsequent follow-up CT examinations are performed with increasing noise index levels (increments of five per follow-up) of up to 35. It is also important to realize the downfall of blanket increase in noise index as very high noise levels can cause severe graininess of images and influence the accuracy of diagnosing small calculi. Other approaches that can be equally effective in the reduction of radiation dose include decreasing the tube voltage, limiting the scanning range, and increasing slice thickness (see Figure 8).

Reducing the tube voltage not only has radiation dose benefits but also yields images with improved contrast, which is particularly advantageous in the diagnosis of calcified urinary stones. Reduction in the tube voltage from 120 to 90kVp has been found to reduce the radiation dose by 35–57%. However, low tube voltage results in degradation of image quality from noise and artifacts, which can hamper the detection of small stones. Hence, low voltages (80–100kVp) for reduction of the radiation dose are to be used in patients weighing <150lb. In those weighing between 150 and 250lb, a tube voltage of 120kVp gives a good balance between radiation dose and image quality. In heavy patients (>250lb), 140kVp with ATCM is recommended for radiation dose efficiency.

Limiting the scanning range is beneficial in patients who are on follow-up imaging for urinary calculus disease. A default scan range for renal stone evaluation routinely involves scanning from the dome of the diaphragm up to the pelvic floor. Restricting this to include only the kidney, ureter, and bladder can reduce radiation dose, which is equivalent to 15–20 slices. In addition, performing focused anatomical exams with scanning limited to the areas of interest can also limit radiation exposure, e.g. scanning limited to renal area to assess residual stone burden after urological intervention. Use of 5mm-thick slices for diagnostic acquisition supplemented by 2.5–3mm-thick coronal reformations is another approach to reduce the radiation dose without loss of diagnostic quality for stone detection. Use of 5mm-thick slices instead of the routine 1–3mm-thick slices can reduce the radiation dose by 30–50%.

There are concerns about using very-low-radiation-dose techniques alone for CT for diagnosis of urolithiasis, as it can degrade image quality in obese patients and there is a possibility of missing an alternate diagnosis in select patients with suspected urinary calculi. However, careful selection of the scan parameters and the approach discussed above can facilitate the dual goal of reduced radiation exposure and optimized image quality.

Future Directions

Continuing advances in CT technology herald a bright future for the detection and characterization of urolithiasis. Development of better
image reconstruction techniques will allow acquisition of improved-quality images with a low-dose technique. An innovative reconstruction algorithm, the adaptive statistical iterative reconstruction (ASIR) algorithm developed by GE healthcare, achieves 50% dose reduction with image quality similar to the standard-dose techniques. Similar creative innovations by other vendors will soon allow acquisition of diagnostic-quality images with a significant reduction in radiation dose. On the diagnostic front, the development of computer-aided diagnosis (CAD) for the detection of renal stones is likely to have a major impact in the diagnosis of renal stones. CAD algorithms can be designed based on HU and can be optimized to detect calcium stones. CAD, if successfully implemented, has the potential to hasten the detection of urinary calculi.

To conclude, MDCT has a great impact today in the management of patients of urolithiasis. From the initial detection of the stones in patients with acute flank pain to planning treatment strategies and following up patients after treatment, MDCT has a crucial role to play. However, with the increasing use of CT for evaluation of stone disease, it is imperative that the radiologist be aware of radiation dose issues and take measures to reduce radiation dose and also optimize image quality.

References