Renal Imaging in Stone Disease: Which Modality to Choose?

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ABSTRACT

Numerous imaging modalities are available to the provider when diagnosing or surveilling kidney stones. The decision to order one over the other can be nuanced and especially confusing to non-urologic practitioners. This manuscript reviews the main modalities used to image stones in the modern era – renal bladder ultrasound, Kidney Ureter Bladder plain film radiography (KUB), magnetic resonance imaging (MRI), and non-contrast computerized tomography (NCCT). While NCCT has become the most popular and familiar modality for most practitioners, particularly in the acute setting, ultrasound is a cost-effective technology that is adept at monitoring interval stone development in patients and evaluating for the presence of hydronephrosis. KUB and MRI also occupy unique niches in the management of urolithiasis. In the correct clinical setting, each of these modalities has a role in the acute workup and management of suspected nephrolithiasis.

KEYWORDS: Renal imaging, stone surveillance, ultrasound, KUB

INTRODUCTION

Nephrolithiasis is a common disease, affecting nearly 9% of the U.S. population and resulting in over one million emergency department visits each year.[1,2] With changing technology, practice, and surgical techniques the landscape of renal imaging for kidney stone evaluation has evolved over time. There are a variety of options that are utilized with varying degrees of sensitivity, risk, and cost. All imaging modalities must be able to determine the presence or absence of stone either by directly identifying the stone or identifying secondary signs of stone presence. It is helpful if the imaging modality can localize the stone and estimate its size, as this information may inform the likelihood of spontaneous stone passage vs. need for surgical intervention. Additionally, visualization of adjacent structures can allow for optimal surgical planning when deciding which surgical approach to pursue (such as endoscopic vs. percutaneous vs. open). Gleaning information on stone density and quality may provide additional information on the likely composition of the stone, which may alter the care plan for the patient. Finally, imaging is critical for surveillance and confirmation of a technically successful intervention. Herein, we outline the most commonly utilized imaging modalities for assessment of nephrolithiasis including: renal bladder ultrasound, Kidney Ureter Bladder plain film radiography (KUB), magnetic resonance imaging (MRI), and non-contrast computerized tomography (NCCT). We describe common advantages and pitfalls of each modality to help guide imaging selection in patients with suspected stone disease. Further developments are expected to enhance these imaging modalities in the future and improve our ability to accurately and safely diagnose and manage nephrolithiasis.

RENAL BLADDER ULTRASOUND

The use of ultrasonography in the management of nephrolithiasis can be traced back to 1961, when Schlegel and colleagues first published on its use for the intraoperative localization of renal stones.[2] Ultrasonography remains a commonly used imaging modality in assessing for obstructing urinary processes. Its attraction lies in its wide availability, low cost, and noninvasive nature. It is also the safest imaging modality at present, as it omits the need for ionizing radiation and the risk associated with intravenous contrast administration. Ultrasonography has been shown to have increased accuracy in children due to their smaller body habitus and reduced skin-to-stone distance.[3] Given this, ultrasound is a first line imaging modality in the evaluation of pediatric patients and pregnant patients with renal colic symptoms.[4]

Many studies have investigated whether ultrasound is sensitive enough to detect clinically significant nephrolithiasis. The reported sensitivities for stone detection vary widely in the literature, ranging from 3–98% depending on whether direct stone visualization was required or if indirect evidence of stone presence (such as hydronephrosis, twinkle artifact, absence of ureteral jet on Doppler) were sufficient.[5] This wide range is likely due to variations in technique, body habitus, patient population, and sonographic reference standards. Ultrasound is notoriously known for its poor detection of small stones less than 3mm in size which might not produce a shadow. Stones located within the mid-ureter are also challenging to detect due to interference by bowel gas and variations in penetration depth along the ureter's course. Non-obstructing renal stones may also be missed in a decompressed system without hydronephrosis as it can be difficult to distinguish an echogenic stone from echogenic central sinus fat in the kidney or vascular calcifications.[4] Furthermore, when stones are detected, ultrasound often overestimates their size as stone edges are typically ill-defined.[3] Sensitivity is increased in younger patients under age 35 as well as patients with low body mass index.[6] Ultrasound combined with KUB has also been shown to increase sensitivity.[7] Despite its overall lower detection rate than conventional NCCT, multiple studies have demonstrated that ultrasound is unlikely to miss stones that ultimately would require surgical intervention.[8]

In the acute setting, point-of-care ultrasound has also been investigated as a first-line imaging modality for the diagnosis of nephrolithiasis. In patients with equivocal presenting symptoms, it may be used as a screening tool for the presence of hydronephrosis and guide decision making on whether formal imaging for the presence of nephrolithiasis should be pursued. Overall, utilizing formal or point-of-care ultrasound does not preclude the ability to obtain a NCCT if results are not definitive, and delayed vs. immediate NCCT in the emergency room setting does not appear to impact morbidity or cost of the emergency department visit.[9,10]

In addition to diagnosis, ultrasound is widely used in practice for stone surveillance. Routine imaging is required to ensure that patients who undergo non-operative trial of stone passage have, in fact, successfully passed their stone. Surveillance imaging is also recommended post-operatively after stone treatment to assess stone clearance rates. Patients who have known non-obstructing renal stones may elect for serial surveillance of stone growth over time rather than surgical intervention. Recurrent stone formers also may require interval imaging as part of their stone disease care plan. The frequency of surveillance imaging acquisition is variable and not standardized. In keeping with the principle of ALARA (as low as reasonably achievable) and efforts to minimize additive radiation exposure, ultrasound is an appealing choice for long-term stone surveillance.[11,12] However, given its limitations as described above, ultrasound may miss small residual or asymptomatic calculi and therefore underestimate the need for intervention.[13] This can lead to undertreatment and complications of indolent obstruction over time such as recurrent symptomatic events and even long-term renal injury.[14]

Overall, research is ongoing to develop stone-specific ultrasonographic algorithms to maximize stone contrast, increase resolution, and improve stone sizing accuracy both for the diagnosis and subsequent surveillance of nephrolithiasis.[15] In summary, ultrasonography is less sensitive and specific than other imaging modalities for the detection and accurate sizing of stones. However, it is safe, cost-effective, and does have diagnostic utility in the correct patient population and clinical circumstance.

KIDNEY URETER BLADDER PLAIN FILM RADIOGRAPHY (KUB)

As the earliest available imaging modality, the KUB is often overshadowed in discussions of NCCT scan versus ultrasonography for imaging urolithiasis. The sensitivity and specificity of the KUB has been estimated at 57% and 76%, respectively.[16] Importantly, when considering larger stones (>5 mm), which are more likely to be clinically significant, the KUB has a higher sensitivity of 87.5%.[17] While the KUB can provide information on stone size and location in many circumstances, its one-dimensionality and lack of information regarding anatomic details of the collecting system and surrounding structures are major limitations in surgical planning. However, a few situations remain where the KUB provides valuable clinical information with the added benefit of easy accessibility, low cost, and relatively low radiation exposure.[18]

One such example is in determining a patient's candidacy for treatment by extracorporeal shock-wave lithotripsy (SWL). In order for a stone to be treated by SWL, it must be visible on KUB to allow for intraoperative stone targeting and live assessment of stone fragmentation. Efficacy of SWL treatment is influenced by parameters such as skin-to-stone distance and stone composition. For example, a skin-to-stone distance of less than 10 cm is considered favorable for renal stones, and stone attenuation of less than 900-1000 Hounsfield units helps predict successful treatment by SWL.[19] These parameters should initially be determined by CT imaging; however, subsequent SWL planning would not require repeat CT scans, presuming the recurrent stone is likely of the same composition. These patients would instead only require a pre-operative KUB. Benefits of SWL include the least morbidity and lowest complication rate of all stone treatment options.[20,21] After the procedure has been completed, KUB is also useful for assessing residual stone burden. Therefore, SWL is a procedure where KUB has a unique utility in the pre-operative, intra-operative, and post-operative assessment and management of urolithiasis.

The other major role of KUB is in surveilling adult patients who are being followed for asymptomatic stones. The low radiation exposure compared to NCCT is particularly important to consider for young recurrent stone formers who will undergo decades of stone surveillance imaging. The low cost and easy accessibility also make KUB an attractive option when compared to other modalities such as US and NCCT. Therefore, literature suggests obtaining a KUB annually as part of routine surveillance for stones in asymptomatic adult patients, presuming the stones are radiopaque.[22]

Disadvantages of the KUB include the lack of anatomic details of the collecting system and surrounding structures as mentioned above, but there are several additional limitations to discuss. One such limitation is the possibility of stones being obscured by overlying bowel gas and stool or by overlying bony structures (commonly the ribs or pelvis).[23]

Another issue is differentiating stones in the collecting system (particularly the ureters) from adjacent vascular calcifications (like phleboliths in the pelvic veins).[24] Also, KUB is not able to detect all stone compositions – some stones, such as cystine and struvite, are poorly visualized on KUB, while other types such as uric acid or matrix are radiolucent and not able to be seen at all.[4] Thus, KUB plays a very nuanced role in the realm of stone imaging and should be considered only in the correctly selected patient.

MAGNETIC RESONANCE IMAGING (MRI)

MRI can be used as an adjunctive diagnostic study in the management of pregnant patients who are suspected to have symptomatic urolithiasis, but MRI is otherwise rarely used in clinical practice. Its limitations in the management of stone disease are pragmatic in nature, rooted in high cost and issues with accessibility. For instance, MRI usually costs approximately three times more than a NCCT.[4] Additionally, the sensitivity of MRI is estimated to be 82%, which is higher than KUB and US, but lower than NCCT.[16] Although adjustments can be made to the imaging sequence to improve sensitivity, conventional MRI sequences display stones as signal voids that may be missed when small (<4 mm) or difficult to distinguish from other etiologies (i.e. soft tissue masses, blood products).[25] The main benefit of MRI for pregnant patients is that it avoids radiation exposure for the fetus. Although not practical to obtain for all pregnant patients as the initial diagnostic test, it should be ordered for pregnant patients with clinical history suspicious for urolithiasis and a nondiagnostic renal bladder ultrasound.[4]

NON-CONTRAST COMPUTED TOMOGRAPHY (NCCT)

NCCT has become a cornerstone of imaging for many abdominal and specifically urologic pathologies. Its advantages stem from its high resolution and image quality, as well as its wide availability in hospitals and clinical settings. Unlike other comparative modalities, NCCT images are less susceptible to confounding patient-specific factors such as body habitus or anatomic variation (i.e., duplicated collecting system). It is also able to image the entire collecting system from kidney to ureter to bladder with excellent resolution. The accuracy of diagnosis for renal colic has been cited to be nearly 95–98% sensitive and 96-100% specific.[26] It is not surprising, therefore, that NCCT is now performed in more than 90% of patients who are diagnosed with kidney stones, largely due to the consistency, speed, and accuracy of its images.[27,28] For urologists, NCCT confers an advantage for surgical planning because it provides valuable information about the overall stone burden, size, density and location that can help determine the appropriate treatment to offer patients (ie: endoscopic vs. percutaneous vs. open approach).[5,26,29,30] NCCT is also helpful in the emergency room setting for counseling patients on their chance of spontaneous passage when they present with an acute stone event (i.e., renal colic, urinary infection, acute kidney injury).[31]

A clear advantage of NCCT is its ability to detect all types of urinary stones, some of which are radiolucent or poorly visualized by other modalities.[27] The use of HU to characterize the density of stones on CT is useful in predicting treatment challenges and selecting the appropriate surgical treatment option.[26] Knowledge of stone density can help guide treatment discussion toward less invasive techniques for treatment such as SWL for lower density stones.[19,26] Additionally, the anatomic detail provided by NCCT is critical for surgical planning in patients undergoing percutaneous nephrolithotomy (PCNL) for stone treatment, as NCCT can identify if there are anatomical abnormalities that would necessitate alternative access options.[27] Lastly, CT can diagnose non-urologic explanations for patient symptoms that can be misattributed to stone disease. Other causes of flank and abdominal pain that mimic renal colic may be due to gynecologic, vascular, musculoskeletal, or gastrointestinal problems that can be detected in nearly one-third of non-contrast CT studies.[5,32]

However, NCCT imaging does not come without risk. Its ionizing radiation remains a concern, particularly in high-risk populations such as pregnant patients, children, and those who are recurrent stone formers. In these populations, the risk of radiation exposure may outweigh the benefits conferred by NCCT imaging. Routine NCCT can deliver a radiation dose of approximately 8 to 16 milliSieverts (mSV) compared to 0.5 to 0.9 mSV for KUB.[33] Fortunately, the implementation of low-dose CT scans has mitigated this risk substantially. A low-dose CT scan delivers a radiation dose between 0.5 to 2 mSV. In fact, the American Urologic Association and American College of Obstetrics and Gynecologists guidelines recommend low-dose CT for confirmation of stone presence in pregnant patients with flank pain and hydronephrosis, with nearly no change in accuracy when compared to regular NCCT scan.[33-36] Less is known regarding the long-term effects of frequent NCCT scans for those with recurrent renal stone burden and in developing children. There is concern that frequent radiation exposure increases the risk of developing certain malignancies such as leukemia and thyroid cancer.[28] Therefore, NCCT is not the modality of choice in the pediatric population and should be used sparingly in stone surveillance care plans. Overall, the risk associated with radiation exposure should be weighed carefully with the overall benefit that NCCT confers in the diagnosis and management of nephrolithiasis.

CONCLUSIONS

Ultrasound, KUB, MRI, and NCCT are all imaging modalities that can be used to effectively evaluate for nephrolithiasis. While non-contrast CT remains a cornerstone for the diagnosis of kidney stones due to its high sensitivity, the risks associated with radiation exposure make it a less desirable option in certain patient populations. Ultrasound provides less information than NCCT but is safe, cost-effective, and has high accuracy at detecting clinically significant nephrolithiasis. It is, therefore, the preferred imaging modality for pediatric and pregnant patients. KUB plays a role in specific clinical scenarios such as routine surveillance for stones in asymptomatic adult patients and in patient selection for SWL. MRI may be considered as an adjunctive test when necessary for pregnant patients. When deciding between these imaging modalities in a patient with concern for renal colic, it is important to consider these advantages and drawbacks in the context of the presenting clinical scenario.

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Disclosures

The authors have no conflicts of interest to disclose.

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