Ureteral calculi imaging: a literature review comparing plain film studies, contrast media studies, ultrasound and computed tomography

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Abstract Purpose: Through a study of the literature this paper aims to investigate the imaging pathway which should be undertaken by patients presenting to the emergency department with renal colic and flank pain. Method: The British Journal of Radiology, Journal of Endourology, Radiology, RadioGraphics, American Journal of Radiology and Adult Urology were searched to find any previous studies into this area through the use of keywords: calculi, renal, computed tomography (CT), plain imaging, abdominal, ultrasound, intravenous urogram (IVU) and x-ray. Conclusion: This literature review determined that the use of non-enhanced helical CT scanning of the abdomen and pelvis should be utilised as the initial imaging technique. CT is able to demonstrate all stones, can be performed rapidly and can diagnose other pathologies which may be mimicking renal colic. Plain film and contrast imaging studies including intravenous urography (IVU) are seen as being of little diagnostic value for frontline identification due to their inability to demonstrate a large number of stones due to size, location and composition. Ultrasound has been shown to be of use as a tool for pregnant or paediatric patients, however its inability to accurately demonstrate the ureters and diagnose extra-urinary pathology limits its use for the general population. The use of low-dose CT is also discussed, and its use advocated for patients with repeat presentation of these symptoms. As more education is provided into this area, the authors believe this will become the modality and technique of choice. An imaging pathway flowchart devised by this review is provided.

Keywords: calculi, contrast studies, CT, imaging, IVU, low-dose CT, renal stone, ultrasound.

Introduction

In patients presenting to the emergency department with renal colic (spasmodic severe pain) and flank pain, a workup for the detection of any ureteral stones causing obstruction and hence a painful passage of the calculi is undertaken. Previously, this was achieved through the use of a planar radiograph of the abdomen which included the kidneys, ureters and the bladder; commonly referred to as a KUB. This was often accompanied by an intravenous urogram (IVU), which included tomography of the kidneys and the administration of an iodinated contrast media. In 1995, non-contrast CT was recommended for diagnosis of ureteral calculi, and ultrasound has been proposed as a radiation free possibility.

There are many imaging pathways a physician can use to determine a patient’s pathology, this can make it difficult for doctors to determine which path is most appropriate for their patient. This paper aims to investigate the current literature to determine which imaging modalities are currently most suitable for use in the detection of ureteral calculi and present a single article for reference, which incorporates all of the current modalities. This will allow patients to be managed in a more effective manner thereby assisting both the patient and the health care institute.

Plain film imaging – KUB

A KUB has typically been the initial pathway for patients presenting with renal colic. As such, all treatment strategies are based upon measurements from these planar images. A previous study by Tann, Silverman and Shuman identified that 90% of stones less than 4 mm and 50% of stones 4–7 mm will pass spontaneously while 8 mm and larger stones will rarely pass without intervention. The 2001 study by Zagoria, Khatod and Chen demonstrated that 79% of stones larger than 5 mm will be visible on a KUB; while only 37% of stones less than 5 mm will be seen. This detection rate of only 37% for smaller stones may appear very low, however the majority of stones which will not pass spontaneously and hence require intervention will be visible on plain film imaging. However, it is believed that these KUB measurements may overestimate stone size by 15–20% due to the object-film distance causing magnification, and as the size and location of obstructing calculi are the primary factors for determining treatment, accurate calculi measurements are vital. As object film distance can vary due to patient habitus, this can again cause a variation in magnification and therefore impact upon management strategies.

An advantage of performing a KUB is the knowledge that any calculus identified on plain film will also be visible under fluoroscopy. This is important as fluoroscopy is utilised during extracorporeal shockwave lithotripsy for treatment of large calculi, which will not pass spontaneously. Any calculus, which is initially demonstrated on planar imaging, can be monitored via this method also. The use of only the KUB can result in a much lower radiation burden for the patient, with KUBs only administering approximately one-tenth the dose of a CT. The time
taken to perform a KUB is also relatively short, with an ambulant patient being able to be imaged in under two minutes. The medical costs are also minimal.

The main disadvantage of a KUB is that overlying bowel gas and bone can obscure the identification of a calculus. Further disadvantages are that it is difficult to differentiate between ureteral stones, gallstones and phleboliths and evidence of recent stone passage cannot be determined. As 10% of calculi are uric acid based, rather than calcium, these uric acid calculi will be radiolucent and hence will not be visible on a KUB. Increased patient body habitus will also reduce the diagnostic capabilities of a KUB as the image will have reduced radiographic contrast making detection of a calculus more difficult.

The key disadvantage of the KUB is its inability to demonstrate extra-urinary pathology which may mimic the symptoms of renal colic. These mimicked symptoms can occur as the kidneys share their pain fibres with various visceral organs and the body wall thereby allowing the pain sensation to be conducted to the kidney area.

Intravenous urography

The intravenous urography (IVU) was historically the primary tool for the investigation of renal colic, however it shares many of the same disadvantages associated with the planar KUB. These include an inability to demonstrate small calculi, overlying bone and bowel gas/faeces obscuring calculus identification, difficulty in differentiating phleboliths, an inability to demonstrate uric acid stones and difficulties in imaging obese patients. While these disadvantages are common to all planar imaging techniques, the IVU also has its own pertinent disadvantages.

As iodinated intravenous (IV) contrast is utilised, this study cannot be performed on patients with poor renal function as this may result in renal failure. There is also the risk of the patient suffering adverse reactions including anaphylaxis, which may be life-threatening. Due to the introduction of the IV contrast, in some cases the precise site and size of radio-opaque stones can be obscured and difficult to determine.

Unlike the KUB which can be performed very quickly, an IVU can take many hours to perform, particularly if the patient has a severe obstruction which requires additional imaging and also increases the patient dose. This makes an IVU potentially a time-
The major advantage touted for an IVU is its ability to provide functional information such as the degree of urinary obstruction caused by a calculus. However, as the major determinates in patient management are stone size, location and the patient’s symptoms this information is of little advantage.

**Ultrasound**

Ultrasound (US) is commonly recommended for use in diagnosing ureteral calculi as it does not utilise ionising radiation, no intravenous contrast media is required, and the examination only takes approximately 30 minutes once the patient’s bladder is full. Ultrasound has been demonstrated to have a sensitivity of 37–64% for calculus detection and a sensitivity of 74–85% for the detection of acute obstruction. The specificity for calculus and obstruction detected by ultrasound is 95–100%. However, due to bowel gas commonly obscuring the ureters, ultrasound performs ineffectually for the identification of conditions of the ureter. This results in the large range of reported sensitivities of ultrasound. Large patient habitus also reduces the accuracy.

An ultrasound practice of assessing the ureteral jets using colour flow has been discussed as an additional technique to help in the detection of calculus. The main limitation of this technique is that 30% of patients with a calculus will have normal jet flow and an abnormal jet flow may be caused by pathology other than a calculus.

The main disadvantage of ultrasound is that a renal ultrasound routinely only includes the kidneys, ureters and bladder. As such, any other pathology that may be causing the symptoms can go undetected. This is not due to the inability of ultrasound to assess these conditions, rather that these additional areas are not routinely imaged. A possible reason for this is that if the entire abdomen and pelvis were to be scanned it would dramatically increase the examination time. There are also different preparations required for appropriate imaging of the various structures. Additionally, many pathologies in female patients which mimic ureteral calculi occur at the ovaries, this would require a transvaginal examination to be carried out for optimal assessment, which increases the examination time and makes it a much more invasive procedure.

The primary advantage of ultrasound is that it is radiation free, and hence can be utilised on radio-sensitive members of the public such as pregnant woman and paediatrics without risk of radiation dose.

**Computed tomography**

A computed tomography (CT) scan of the abdomen is now recognised as the gold standard in the identification of ureteral calculi with a sensitivity of 95–98% and a specificity of 96–100%. The high radiation dose received by patients makes CT impractical for monitoring purposes especially as young adults are frequently affected. Dose considerations are particularly pertinent as almost 50% of all patients who are diagnosed with ureteral calculi will suffer from recurrent stone problems within five years of initial occurrence, 50–60% within 10 years and 75% within 20–30 years. As such many of these patients will undergo multiple radiological examinations throughout their lives for this pathology making the high radiation doses received during each
examination of greater concern.

Identifying calculi

The advantage of utilising CT is that all stones present will be detected regardless of size, composition and location. The exception of this is the indinavar stone which occurs in patients with the human immunodeficiency virus (HIV). This stone occurs due to the medication taken crystallising the urine and as such can be undetectable on CT. Unlike planar imaging and ultrasound, overlying bone and bowel does not obscure stones and differentiation between ureteral stones, gallstones and phleboliths can be made.

A 2000 study by Assi, Platt, Francis, Cohan and Korobkin demonstrated that if a stone was identifiable on the initial CT scout (topogram, scanogram etc.) then it would be visible on a KUB. As 13% of stones that will be visible on a KUB are not identified on the scout, another 2000 study utilises a technique of measuring the Hounsfield Unit (HU) value of the stone. If the stone’s value is below 200 HU it will not be visible on the KUB, if it is between 200–300 HU, it may be visible (generally if the stone is greater than 5 mm), and if the stone is greater than 300 HU then it will definitely be visible on the KUB.

By utilising these techniques one should be able to ascertain the probability of a stone being visible on follow-up KUB films without increasing a patient’s dose by always performing an initial KUB at time of presentation. A KUB image is only necessary if the CT scan indicates that the stone has a range of 200–300 HU and is less than 5 mm in size. Knowledge of the stones position from the CT should demonstrate the possibility of overlying bony structures, which may require oblique KUB films to allow visualisation of the stone.

Measuring calculi

As calculi size is one of the primary determinates for patient management it is important to identify any variation in measurements between planar radiography and CT. This is significant as the guidelines available on patient treatment strategies, such as from the American Urological Association, have been established using measurements from planar imaging and any variations between the modalities in reported stone size will effect the management of the patient.

A 2003 study by Appledorn, Ball, Patel, Kim and Leveillee investigated the effect of counting the number of 5 mm slices a calculus was demonstrated on, as a means of measuring the size of the calculi. If a stone was only visualised on one slice, it was classed as being 5 mm or less, if it appeared on two adjacent slices it was classed as being 10 mm or less etc. From their study, the authors determined that by using this technique, the size of the calculi could be underestimated by 30–50%. This may cause patients who have calculi which are less than 8 mm and will therefore most likely pass spontaneously being pushed into this higher category. As a result of the over-estimation of size, unnecessary surgical intervention may be undertaken when conservative management may have been all that was necessary.

In contrast, Dundee, Bouchier-Hayes, Maximolla, Dowling and Costello measured both the length and width of each stone by using the calibration scale provided by the CT scanner. The largest dimension was recorded for all stones and compared to the results obtained from the KUB images using manual callipers. These results determined that CT underestimated the size of the stone by approximately 12% compared to the KUB. This had the opposite effect of the 2003 study, with patients who may of required intervention being treated conservatively due to underestimation of the calculi size.

It is clear that the techniques utilised by Dundee, et al. are more precise, and as this specific measuring technique has been shown to underestimate the size of the calculi and hence lean towards a more conservative approach it would appear to be the best technique to utilise initially rather than performing unnecessary intervention due to overestimation of the calculi. This variation in reported calculi size between CT and planar imaging reveals the need for development of guidelines based on CT measurements rather than planar images to be established.

Differential diagnosis for renal colic

Another major advantage of CT is its ability to identify secondary signs such as ureteral dilation/inflammation and changes in perinephric fat which can indicate that a stone has recently been passed. CT can also demonstrate other causes of the patient’s symptoms which may mimic those of renal colic. Commonly encountered pathologies are included in Table 1. A 2003 study reported that 16–45% of all patients who presented with flank pain had extra-urinary causes which were identified by non-enhanced CT, thereby providing a diagnosis without any additional studies being required. Due to these advantages of non-enhanced CT, it has also been shown to dramatically increase the confidence of requesting physicians in their patient treatment strategies.

Low dose CT

In recent years there have been advancements within the field of CT, which have resulted in the lowering of the patient’s effective dose. These advancements include the use of solid-state detectors, which are more sensitive than older helium gas detectors, reduction in rotation time to 0.5 sec and the increased ease in altering the mAs by the performing technician.

A 2006 study by Poletti, Platon, Rutschmann, Verdon, Schmidlin, Iselin, et al. investigated the advantages of utilising low dose abdomen CT as the initial imaging rather than plain imaging. They demonstrated that low dose CT was able to identify all stones greater than 3 mm, and that 69% of patients undergoing low dose CT did not require any additional imaging studies, such as ultrasound or normal CT, compared with only 23% of those who were initially investigated by plain imaging.

Table 1. Commonly demonstrated pathologies seen on CT which may mimic ureteral calculus.

<table>
<thead>
<tr>
<th>Gynaecologic Conditions</th>
<th>Ovarian Cysts</th>
<th>Tubo-Ovarian Abscesses</th>
<th>Dermoid Cysts</th>
<th>Endometriomas</th>
<th>Ovarian Neoplasms</th>
<th>Cervical Cancer</th>
<th>Degenerating or twisted fibroids</th>
<th>Ectopic pregnancy</th>
</tr>
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<tbody>
<tr>
<td>Gastrointestinal Diseases</td>
<td>Appendicitis</td>
<td>Diverticulitis</td>
<td>Abdominal Hernias</td>
<td>Small Bowel Obstruction</td>
<td>Intussusception</td>
<td>Colon Carcinomas</td>
<td>Inflammatory Bowel Disease</td>
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<tr>
<td>Pancreatic and Hepatobiliary Disorders</td>
<td>Gallbladder stones</td>
<td>Bile duct stones</td>
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<td>Vascular Diseases</td>
<td>Ruptured abdominal aortic aneurysms</td>
<td>Aortic dissection</td>
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imaging. This resulted in a 50% reduction in the mean patient radiation dose.\(^1\)

Another study\(^2\) into the use of low-dose CT demonstrated that low mAs could be used. The authors suggested that for patients with a BMI of less than 35 kg/m\(^2\), 30 mAs may be used while for larger patients 60 mAs should be utilised. When 30 mAs is used, the mean effective dose was measured at 1.2 mSv in men and 1.9 mSv in women.\(^3\) This is approximately an 89% reduction in the dose received from a standard multi-detector CT examination. This CT dose is similar to that received from a three view IVU and it is lower than the dose from a six view IVU which is reported as being 2.5 mSv.\(^4\) In cases where the ureter is seriously obstructed more than six films are often required for the IVU, which would increase the patient’s dose. While 60 mAs is recommended for larger patients,\(^6\) Huda, Atherton, Ware, and Cumming\(^7\) demonstrated that this increased mAs does not necessarily relate to an increased dose to the radiosensitive pelvic organs such as the bladder, colon and gonads as they are more centralised causing the effective dose to be lower than that received by a smaller patient.\(^8\) The 2003 study by Tack, Sourtzis, Delpiere, Maertelaer and Gevenois\(^9\) also demonstrated that utilising a low-dose technique did not reduce the modality’s ability to detect extra-urinary pathology, which is highlighted as a major advantage of conventional CT.\(^10\)

As more education is provided into the use and benefits of utilising low-dose CT, low-dose CT has the capacity to become the frontline tool for the initial imaging technique for patients suffering from renal colic. The biggest hurdle will be

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**Figure 7**: Flowchart demonstrating the imaging pathways which should be undertaken when a patient presents with flank pain.
for requesting doctors to become as confident in low-dose CT diagnosis as they currently are for conventional CT scanning. More education will also be required for radiographers and radiologists in the implementation of low-dose protocols. Currently low-dose CT is mainly utilised for monitoring radio-opaque stones or for use in patients who have been previously diagnosed with urinary calculi.15

After undertaking a comparison of these imaging modalities used in the detection of renal calculi, a flow-diagram to demonstrate the imaging pathways has been created. This flow-diagram should be used for patients presenting with renal colic. The flow-diagram is demonstrated in Figure 7. The use of this flow-diagram indicates the modality which should be utilised to best demonstrate the pathology and assist in the reduction of the patient’s radiation dose.

Conclusion

From this literature review, the authors have demonstrated that there is limited benefit in performing planar KUB as the initial imaging for detection of ureteral calculi. The practice of performing an IVU is redundant and its ability to provide functional information is of little benefit in regards to patient management strategies. As the sensitivity for ultrasound in detecting calculi varies widely dependant upon stone size, location and patient habitus/preparation, it should only be used as the primary diagnostic tool in radiosensitive members of the public such as paediatrics and pregnant women.

A CT of the abdomen should be the initial imaging pathway and reporting doctors should assess the urinary tract as well as looking for possible other causes of symptoms. From the information ascertained through undertaking a CT examination including the size of the stone, its HU value and whether it is identifiable on the scout image, the likelihood of a stone being visible on a KUB for follow-up could be determined. As such, the only time a KUB would need to be performed is if the stone had a range of 200–300 HU and is less than 5 mm in size. This planar image is only taken to determine whether the stone will be able to be monitored via planar imaging or require CT. Other than calculi, which fall into this specific category, a planar KUB is not required, prior to follow-up. Currently more research is required into the correlation between actual stone sizes and those as measured on plain imaging to that of CT, to allow correct patient management strategies to be made from this modality.11

A decrease in diagnosis time would be achieved by utilising CT as the primary imaging modality, rather than IVU or ultrasound due to a CT scan taking less than five minutes to perform. The authors believe this would improve patient flow in both radiology and the emergency department, and hence improving patient satisfaction with their medical care.

The use of low-dose CT is still being researched, however current studies are demonstrating the accuracy of this technique for diagnosing clinically significant stones, alternative pathologies and reducing the number of radiological procedures the patient must undergo for a diagnosis.19 The ability to make a diagnosis using a much lower radiation dose than traditional CT parameters makes it a highly desirable imaging technique particularly as many patients suffer from recurrent stone disease.9

The possibility of producing diagnostic images at lower dose rates is an area of radiography which requesting doctors, radiographers and radiologists should be interested in for the benefit of the patients. As such, more research, education and implementation are required across the entire scope of CT examinations to ensure the original ALARA (As Low As Reasonably Achievable) principle is adhered to and patients are not being dosed unnecessarily or excessively.

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All images included with permission of Hunter New England Imaging.

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References