Symposium

As low as reasonably achievable: Methods for reducing radiation exposure during the management of renal and ureteral stones

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ABSTRACT

Imaging for urolithiasis has evolved over the past 30 years. Currently, non-contrast computed tomography (NCCT) remains the first line imaging modality for the evaluation of patients with suspected urolithiasis. NCCT is a dominant source of ionizing radiation for patients and one of its major limitation. However, new low dose NCCT protocols may help to reduce the risk. Fluoroscopy use during operating room (OR) surgical procedures can be a substantial source of radiation for patients, OR staff and surgeons. It is important to consider the amount of radiation patients are exposed to from fluoroscopy during operative interventions for stones. Radiation reduction can be accomplished by appropriate selection of imaging studies and multiple techniques, which minimize the use of fluoroscopy whenever possible. The purpose of this manuscript is to review common imaging modalities used for diagnosing and management of renal and ureteral stones associated with radiation exposure. We also review alternatives and techniques to reduce radiation exposure.

Key words: Calculi, imaging computed tomography scan, nephrolithiasis

INTRODUCTION

Imaging is a key component in the evaluation and management of patients with urolithiasis. Beyond diagnosis, imaging provides important information that allows urologists to determine the most appropriate treatment modality for the patient. This information includes the size, location and in some cases the stone composition.[1,2]

Plain abdominal radiography kidneys, ureters and bladder (KUB) and excretory radiography intravenous pyelogram have been largely supplanted by non-contrast computed tomography (NCCT) of the abdomen and pelvis (NCCT) for the initial diagnosis and follow-up of urolithiasis.[3-5] Ultrasound has also been used in place of traditional radiography.[6-8]

Patients with urolithiasis are at risk for recurrence and therefore are exposed to significant radiation exposure from imaging studies. Recent studies show growing concern over radiation exposure from imaging studies. NCCT is a dominant source of radiation in these patients. Plain radiography (KUB) and digital tomosynthesis (DT) are other modalities used in the evaluation and follow-up of nephrolithiasis, but incur in less radiation exposure.[9] The effective doses (EDs) for a stone protocol NCCT was 3.04 ± 0.34 mSv. The ED for a KUB was 0.63 and 1.1 mSv for the additional tomographic film. The total ED for intravenous urogram was 3.93 mSv. The ED for DT performed with two scouts and one sweep (14.2°) was 0.83 mSv.[9] Table 1 summarizes ED associated with common imaging modalities used in the follow-up of patients with urolithiasis.[9] Once diagnosed with a stone, a significant number of patients will undergo surgical intervention. Fluoroscopy used during shock wave lithotripsy (SWL), ureteroscopy (URS) and percutaneous nephrolithotomy (PNL) contributes to the overall radiation exposure of patients with urolithiasis.[10-12]

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Table 1: Radiation exposure in the follow-up of patients with urolithiasis

Imaging modality	Effective dose (mSv)
KUB	0.63
Tomographic image	1.1
IVP/KUB with tomography	3.93
Stone protocol CT	3.04
Digital tomosynthesis	0.83

CT=Computed tomography, IVP=Intravenous pyelogram, KUB=Kidneys, ureters and bladder

This article will describe methods to reduce radiation exposure from commonly performed imaging studies for the diagnosis and management of urolithiasis.

EVALUATION OF RENAL COLIC

NCCT is currently considered the first line imaging study for the evaluation of the patient with acute flank pain and a suspected stone. NCCT has a reported sensitivity of 95-98% and specificity of 96-98% for the diagnosis of a ureteral stone in a patient with acute flank pain.[4] Beyond identifying the stone, NCCT allows for evaluation of signs of obstruction associated with ureteral stones. In patients with ureteral stones, NCCT was able to identify hydroureter in 82.7%, hydronephrosis in 80%, peri-ureteric edema in 59% and unilateral renal enlargement in 57.2% respectively.[13,14]

When evaluating patients with acute flank pain, NCCT also has the ability to assess the rest of the abdominal and pelvic organs and possibly identify other causes for pain. In a series of 1000 consecutive NCCT performed for the evaluation of renal colic, an alternative diagnosis for their presenting symptoms was made in 10.1% of the cases.[15]

PRE-OPERATIVE EVALUATION

Beyond the diagnosis stones, NCCT is useful in the pre-operative planning for the treatment of stones. Stone size and location are easily evaluated with NCCT. When planning SWL, the skin to stone distance can be determined on pre-operative NCCT. Prone NCCT can also be useful for the pre-operative evaluation for planning prone PNL. Prone NCCT can determine the anatomic relations of adjacent organs and the pleura with upper pole calyces. This information can help determine the feasibility and risk of complication of an upper pole puncture during prone PNL.

RADIATION REDUCTION

Radiation exposure from medical sources has been steadily increasing over the past three decades.[16,17] There have been approximately more than 62 million computed tomography (CTs) performed in the US by the year 2006.[18] The approximate organ dose from a typical NCCT is similar to the radiation exposure of the atomic bomb survivors.[18] It is estimated that an additional 29,000 cancers could be related to CT scans performed in the US in 2007.[19] Some of the studies show that cancer rates can be doubled in younger patients.[20] Patients with urolithiasis are at increased risk for significant radiation exposure from diagnostic imaging, specifically NCCT. From 1996 to 2007, the use of NCCT to assess patients with suspected stones increased significantly from 4% to 42.5%.[13] The use of NCCT for evaluation of flank pain in the emergency room has increased significantly from 19.6% to 45.5% of patient visits over the past decade. It has been reported that patients undergo a median of 1.7 NCCT in a 1 year period following an acute stone episode.[21]

Fluoroscopy utilized during surgical interventions also contributes to these patients' overall radiation exposure. Given that patients with urolithiasis constitute a high risk population, measures to reduce the amount of radiation these patients are exposed to are extremely important.

SELECTION OF APPROPRIATE IMAGING STUDIES

Proper selection of imaging studies for the evaluation of urolithiasis is an important way to reduce radiation. Whenever possible, radiation free techniques such as ultrasound or magnetic resonance imaging (MRI) should be used. Ultrasound should be considered the first line imaging study for the evaluation of stones or renal colic in pediatric patients and pregnant women. The use of MRI has also been reported for evaluation of renal colic in pregnant women.[22]

The combination of ultrasound and KUB has been shown to have high sensitivity for the diagnosis of ureteral stones and exposes patients to less radiation than a NCCT.

The American Urological Association recently submitted guidelines regarding appropriate imaging selection for the evaluation of ureteral calculi.[23] The authors recommend "low dose" NCCT as the initial imaging modality for a patient with flank pain and a suspected ureteral stone if the body mass index is less than 30 kg/m^2 and a standard dose NCCT if the patient is obese. They recommend a KUB concurrently with the NCCT if the stone is not seen on the scout image. For follow up of radio-opaque stones, they recommend ultrasound along with KUB. In cases of radio-lucent stones, they recommend follow-up imaging with NCCT.

LOW-DOSE CT

Though ultrasound and MRI can be used for the evaluation of patients with urolithiasis, NCCT has the highest sensitivity and specificity for the diagnosis of stones. NCCT is also very valuable for pre-operative planning. The amount of radiation a patient is exposed to from a NCCT of the abdomen and pelvis is dependent on the protocol and machine used, as well as patient characteristics. For a standard NCCT of the abdomen and pelvis performed for the evaluation of stones, the ED has been reported to be as high as 9.6 mSv for men and 12.6 mSv for women.

With the advent of new CT scanner technology and new software, NCCT for the evaluation of urolithiasis can be performed with lower radiation doses while maintaining diagnostic accuracy. These "low-dose" CT scans can greatly reduce the amount of radiation patients with urolithiasis are exposed to. There is no standard definition for "low-dose" CT. A recent meta-analysis evaluating the performance of low dose CT for the diagnosis of urolithiasis defined low-dose CT as applying an ED <3 mSv for the entire examination.[24]

There have been a number of reports assessing the effectiveness of low-dose CT for the evaluation of stones and renal colic.[25] One report compared a standard NCCT at a dose of 7.3-10 mSv versus a low dose NCCT at 1.4-1.97 mSv for the evaluation of acute renal colic. Low dose NCCT had equivalent sensitivities to standard NCCT for the diagnosis of ureteral stones with the exception of ureteral stones <2 mm. In these cases, the sensitivity of low dose NCCT was 68-79% versus 95% sensitivity for the standard dose NCCT.[25]

Low-dose NCCT has been shown to be useful for the follow-up of recurrent stone formers to evaluate for new stone formation or stone growth. In a recent study of 62 patients that underwent NCCT for the detection of urolithiasis. Images were modified by adding image noise to simulate reduced tube current level. Even at a dose reduction of 56%, the authors reported no significant intra-observer or inter-observer differences for the detection of urolithiasis.[26] Low-dose CT has also been reported for the evaluation of renal colic and flank pain in pregnant patients with high sensitivity and specificity.[27]

Low dose NCCT appears to perform as well as standard NCCT for the evaluation of urolithiasis and in cases where NCCT is to be performed, low dose NCCT should be considered the first line imaging study.

FLUOROSCOY

Fluoroscopy is commonly used during surgical procedures to treat patients with urolithiasis including SWL, URS and PNL. Therefore, patients who undergo treatment for stones are exposed to even more radiation. The amount of radiation patients are exposed to during PNL and URS has been quantified using a validated model. Organ specific radiation doses have been calculated and found greatest at the skin entrance, where exposure during left and right PNL, was 0.24 mGy/s and 0.26 mGy/s, respectively.[28] Median fluoroscopic procedure exposures were 43.3 mGy for patients who were undergoing PNL and 27.6 mGy for those patients undergoing URS.[29] There are a number of methods to reduce the amount of radiation patients are exposed to in the operating room (OR).[30-33]

AS LOW AS REASONABLY ACHIEVABLE

The principle of ALARA should always be applied when using fluoroscopy. The practice of minimizing the exposed area and image during fluoroscopy is called collimation. Collimating the image and placing the image intensifier as close to the patient as possible has been shown to decrease during surgical procedures.[34,35] Other techniques include pulsed fluoroscopy, which should be used at the lowest possible frames/s that provides usable image quality to perform the procedure. "Last image hold" should be utilized to save and transfer images to an adjacent screen to be used as a reference during the procedure. Close adherence to the principles of ALARA has been demonstrated to reduce radiation dose during the pediatric interventional radiology procedures.[36]

RADIATION REDUCTION DURING PNL

When performing a retrograde pyelogram to aide in fluoroscopic access during PNL, the use of air instead of iodinated contrast may reduce radiation exposure. A retrospective review of 96 PNL procedures demonstrated that the use of air reduced radiation exposure nearly 50% when compared with contrast, 4.45 mSv versus 7.67 mSv ($P = 0.001$).[30]

The use of ultrasound to obtain access also can reduce radiation exposure by reducing or eliminating the need for fluoroscopy. There have been a number of reports on the use of ultrasound to aide in access during PNL. Two randomized controlled trials have been performed comparing PNL with ultrasound combined with fluoroscopy versus fluoroscopy alone.[7,37] Though these trials demonstrated a reduction in fluoroscopy time with ultrasound, the patients were still exposed to a small amount of radiation from fluoroscopy. The ideal situation to reduce radiation exposure would be to eliminate fluoroscopy altogether. Studies have demonstrated the feasibility and safety of performing PNL with ultrasound alone in a select patient population.

RADIATION REDUCTION DURING URS

The same principles of ALARA apply to fluoroscopy use during URS. In addition, there have been reports on methods to reduce fluoroscopy time for URS. One group of investigators demonstrated a 24% reduction in fluoroscopy time when surgeons were given periodic reports documenting their mean fluoroscopy time compared with that of their peers.[38] In addition, intra-operative techniques have been reported to reduce fluoroscopy time during URS. These measures include the use of a laser guided C-arm, tactile cues for the placement of guidewires, stent placement under direct vision through a cystoscope, use of a designated fluoroscopy technician, and single pulse fluoroscopy mode for portions of the case. When these measures were implemented, the authors reported a reduction in the mean fluoroscopy time during URS from 86.1 s to 15.5 s. This fluoroscopy protocol resulted in an 82% reduction in fluoroscopy time without altering patient outcomes.[39]

RADIATION REDUCTION DURING SWL

The principles of ALARA apply to the use of fluoroscopy during SWL as well. In addition, ultrasound can be used to target the stone instead of fluoroscopy with good success.

SUMMARY

Imaging plays an important role in the evaluation of patients with urolithiasis. NCCT of the abdomen and pelvis is the most sensitive and specific imaging modality for diagnosing stones. Images from NCCT also play an important role in determining the best surgical approach to treat a stone. When NCCT is performed for the evaluation of stones, a “low dose” protocol should be used to reduce the amount of radiation these patients are exposed to. Ultrasound is also useful in the evaluation of urolithiasis. Ultrasound should be considered first line imaging for stones in pediatric and pregnant patients. Ultrasound has decreased sensitivity and specificity for identifying stones compared with NCCT, however it has nearly equivalent sensitivities and specificities for diagnosing obstruction. Plain abdominal radiography is mostly useful for pre-operative planning prior to SWL and as an adjunct to ultrasound. The role of MRI in the evaluation of urolithiasis is limited.

Stone patients are exposed to significant amounts of radiation from diagnostic imaging, primarily NCCT and fluoroscopy in the OR. Proper imaging modality selection helps to minimize radiation exposure. Following the principles of ALARA in the operating room can help reduce the amount of radiation patients are exposed to from fluoroscopy.

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