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Techniques for Minimizing Radiation Exposure During Evaluation, Surgical Treatment, and Follow-up of Urinary Lithiasis

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Abstract Patients receive significant radiation exposure during the diagnosis, treatment, and follow-up of urinary stone disease. This radiation exposure may result in patient harm and is believed to contribute to the risk for malignancy. This review will present current information to allow surgeons to optimize their diagnostic, treatment, and follow-up regimens to allow optimal care of stone disease patients at the lowest radiation dose possible.

Keywords Urolithiasis · Radiation protection · Radiation exposure · Radiation reduction · Management of urolithiasis · Urolithiasis treatment

Introduction

The incidence of kidney stones is increasing in the United States with 1 in 11 people affected, and an estimated lifetime risk of 13 % in men and 7 % in women [1, 2]. Between 1992 and 2009, there was an increase in the number of emergency room (ER) visits from 178 to 340 per 100,000 individuals [3]. It is estimated that 74 % of patients presenting to the ER with flank pain or colic will undergo computed tomography (CT) imaging, and those patients with stones will likely undergo a mean of 2.5 CT scans per stone episode [4].

Radiation exposure during medical evaluation and treatment of urolithiasis is not without risks. It is estimated that 1.5–2.0 % of all cancers diagnosed in the United States may arise from radiation received during CT imaging [5]. Furthermore, reports estimate that CT scans would result in the development of 29,000 cancers in the United States in 2007 alone [5]. Ferrandino and colleagues reported that during the work-up and treatment of a single stone event, patients received an average mean effective dose of 29.7 mSv, with 20 % receiving >50 mSv [6]. For comparison, it is estimated that Japanese atomic bomb survivors received a mean dose of 40 mSv [6, 7]. In addition, patients who present with stones have a 50 % chance of recurrence of stones within 10 years [8]. In February 2010, due to concerns over rising radiation exposure to patients and hazardous side effects including malignancy, the United States Food and Drug Administration issued a white paper specifically targeting CT, fluoroscopy, and nuclear medicine imaging for responsible usage in accordance with the tenets of the ALARA (as low as reasonably achievable) principle [9].

Of concern, a 2004 study of 45 emergency room and 38 radiology physicians found that 91 % and 53 %, respectively, believed that radiation did not increase the risk of malignancy [10]. It is important that all physicians evaluating urolithiasis patients be well informed regarding the effects of radiation and the options for reducing radiation exposure in this population. This review will provide an overview on the responsible use of medical imaging during diagnosis, treatment, and follow-up of urolithiasis patients.

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Biological Effects of Radiation

The term “absorbed dose” refers to the amount of energy deposited per unit mass and is a way to determine the probability of a biologic effect. Absorbed dose is measured in units of gray (Gy) or milligray (mGy). One gray is equal to 1 J/kg [11]. Entrance skin dose refers specifically to the measure of radiation dose absorbed by the skin where the x-ray beam enters the patient. Finally, organ dose describes the amount of radiation experienced by the organs of a patient [12].

Radiation exposure has been found to cause both an immediate deterministic effect and a delayed stochastic effect [13]. The deterministic effects have a short latency period, with a threshold dose of 2–3 Gy (2000–3000 mSv) [13, 14] and can include transient erythema and epilation [11]. In comparison, the stochastic effects (including the development of secondary malignancies) have no threshold and are thought to result from damaged DNA transformation. This effect is directly correlated with the total amount of radiation absorbed [13, 15].

Table 1 lists the mean effective radiation doses that individuals are exposed to during daily life and routine imaging. With so many radiation sources, and their accumulative effects, attempts to reduce unnecessary radiation are important.

Table 1 Typical radiation doses

Procedure	Mean effective dose (mSv) values
CT abdomen [6, 96]	5–10
CT pelvis [6, 96]	5–10
Low-dose CT abdomen/pelvis [37, 97]	2.0–3.5
Ultra low-dose CT abdomen/pelvis [21, 33]	0.5–1.5
CT urogram [98, 99]	10–31
CT pet scan [99]	14.1
KUB [6, 97]	0.7–1.1
Chest x-ray [99]	0.02–1
IVP [6, 97]	1.5–3.5
Renal scan MAG3 [99]	2.6
Bone scan [99]	6.3
Nephrostomy tube placement [99]	3.4
Percutaneous nephrolithotomy (PCNL) [74•, 75]	3–18
Shock wave lithotripsy [88, 90]	1–8
Ureteroscopy [46, 90]	1–7
Background radiation in US	3.11
1 min of continuous fluoroscopy [46, 48]	1–10 mGy/min
Plane flight from NY to London	0.04
Airport full body scan (50 kVp; 120 kVp)	0.9; 0.8 μSv

Reducing Radiation During Work-up for Urolithiasis

The non-contrast CT scan has become the diagnostic test of choice for patients with flank pain and renal colic [16]. CT scans have a sensitivity and specificity of >90 % in diagnosing urolithiasis [17]. In addition, the CT is universally available, does not require contrast, can be performed quickly (multi-detector scanners can scan an abdomen and pelvis in a few seconds), and also may establish other potential diagnoses associated with flank pain or colic [16, 18]. The only major drawback of this modality is the high radiation exposure accompanying conventional CT imaging. A single conventional non-contrast abdomen/pelvis CT is estimated to result in 10–20 mSv of radiation [17] and cause malignancy in 1/1000 patients [19, 20].

Imaging modalities other than CT may also be used to diagnose urolithiasis including plain films, renal tomograms, IVP, ultrasound (US), and MRI. MRI and US have the benefit of no radiation exposure. However, MRI has a low sensitivity of 64–80 % for detecting urolithiasis [21]. While an MR urogram has shown a 96.2 % accuracy in stone detection [22], the MRI acquisition time could range from 30–60 min. In addition, the cost and decreased availability of MRI make it impractical for routine imaging of stone patients.

Renal US has good sensitively for larger renal stones in thin patients but is not very sensitive for ureteral stones. This modality is operator dependent, with a sensitivity ranging from 22 % to 77 % for urinary calculi, and an overall accuracy of 53 % [21, 23]. Image quality may be poor in obese patients [24, 25]. However, in young and thin patients, renal US may have up to an 86.4 % detection rate for renal stones and may be a reasonable first-line imaging modality in this population [26]. Furthermore, when compared to CT, US as the initial imaging modality for suspected nephrolithiasis did not result in a higher rate of complications due to missed alternative pathology (i.e., ruptured abdominal aortic aneurysm, bowel ischemia or perforation, etc.), clinical adverse events, or progressive pain [27••].

Conventional kidney-ureter-bladder (KUB) (0.6–1.1 mSv) is rapid, inexpensive, and results in low radiation exposure, but this modality is limited by a 45 %–59 % detection rate of urinary calculi, and it does not detect radiolucent uric acid stones or cysteine stones [24]. An IVP can be performed with moderate radiation exposure (1.5–3.5 mSv) and has stone detection rates comparable to non-contrast CT scans. However, this technique can be labor intensive, time consuming, and requires intravenous contrast medium, with the potential for allergic reaction and renal deterioration [24].

Thus, although other imaging options exist, non-contrast CT remains the modality of choice for diagnosis of suspected urinary calculi. However, many modifications have been reported to reduce the radiation exposure associated with conventional CT imaging. Recently, dual-energy scanners have been shown to determine stone composition while reducing radiation exposure to a moderate range (2.1–6.6 mSv) [28, 29]. In addition, various modifications of iterative reconstruction have been developed to optimize image quality at lower radiation doses [30].

In recent years, the use of low-dose CT imaging (2–3.5 mSv) has been thoroughly investigated [17, 31–35]. These studies have consistently shown that low-dose CT provides a sensitivity and specificity >95 % and is similar to conventional CT for the detection of both renal and ureteral calculi [31, 36, 37]. Low-dose CT has also shown efficacy in detecting stone composition by measured Hounsfield units [38–41] and may assist in selecting the correct treatment regimen [42].

Ultra low-dose protocols (0.5–1.5 mSv) [33] also work well in most patient populations but may not be optimal in patients with infected obstructed urolithiasis because small 1–2-mm stones might be missed [17]. Similarly, very thin and very obese patients are better imaged with low-dose, not ultra low-dose imaging, as image noise can impair image clarity [32]. Finally, patients with spinal hardware, reservoirs, hip replacements, or other implants may produce image noise that compromises the radiologic detection of calculi in the corresponding areas with both low and ultra low-dose CT techniques.

One potential concern associated with low-dose imaging is that 10–40 % of patients who present with acute flank pain are found to have a non-urological diagnosis such as appendicitis, diverticulitis, or neoplasm [43]. However, information is rapidly accumulating demonstrating the effectiveness of low-dose imaging protocols for a variety of intra-abdominal pathologies [44, 45].

Reducing Radiation Exposure in the Operating Room

The primary source of radiation exposure in the operating room is through fluoroscopy utilized extensively during ureteroscopy, percutaneous nephrolithotomy (PCNL), and shock wave lithotripsy (SWL) (Table 1). While appropriate fluoroscopy can provide important spatial and anatomic relationships, excessive fluoroscopy during surgical stone treatment may expose the patient, surgeon, and operating room staff to significant superfluous radiation exposure. The amount of radiation that the patient is exposed to during fluoroscopy is estimated between 1.1–1.4 mSv per minute [46], with spot films increasing this dose by a factor of 10–60 times [11, 47], but the actual exposure is dependent upon both patient and technical factors [48].

There are several technical and procedural modifications that may be employed intraoperatively to reduce radiation exposure during fluoroscopy (Fig. 1) [48, 49]. Ngo and colleagues found that providing feedback regarding fluoroscopy time reduced fluoroscopy utilization by 24 %, with no change in operative time [50]. Other techniques to improve situational awareness during fluoroscopy include surgeon activation of the foot pedal (not radiology technician or assistant), use of an audible signal generated with each tap of fluoroscopy, setting alarms at short intervals to allow the surgeon to gauge fluoroscopy use (30 s not 5 min), and including the fluoroscopy time in the operative report [48]. Furthermore, use of a modern C-arm equipped with a “last image hold” function, which allows surgeons to analyze saved images without requiring continuous fluoroscopy, may reduce fluoroscopy time by up to 60 % (Fig. 1a) [51].

Increasing the distance from the radiation source to the patient is a reliable way to reduce radiation exposure. As stated by the inverse-square law, the radiation intensity at a given site varies inversely as the square of the distance from the source ($\text{intensity}=1/\text{distance}^2$) [52, 53]. Thus, as the patient’s distance from the radiation source is doubled, the radiation exposure will reduce by 75 %. The C-arm should never be operated without the spacer (Fig. 1b illustrates the clear plastic cylinder placed on the radiation source to maintain a safe distance between the beam source and the patient) in place, as it protects the patient from excessively high levels of radiation [53]. Furthermore, all the operating room staff should maintain the greatest distance from the source that still allows for performance of their jobs.

Collimation (restriction of radiation solely to the area of interest) and shielding are two other strategies to reduce radiation exposure for both patients and staff [48]. The most common shields used by staff are lead aprons. Older versions, only covered the anterior body surface, were heavy and contributed to the numerous orthopedic problems experienced by endourologists [54]. Newer, lightweight lead aprons wrap around the entire body and come in a kilt and tunic, so that the weight is distributed over the surgeon’s shoulders and hips (Fig. 1c). Shielding can result in a nearly 70-fold reduction in radiation exposure to the surgeon [55].

Modifying the settings of the fluoroscopy machine is one of the simplest and most effective techniques to reduce patient radiation exposure during endourologic surgery. Most C-arms are operated in the automatic exposure control setting, which increases exposure in order to provide the highest quality image possible, for example, increasing the radiation dose for increased penetration in obese patients. However, many steps during endourologic procedures (like locating a ureteroscope or guidewire) can be performed at much lower exposure levels. Modestly decreasing the peak kilovoltage (kVp), while significantly reducing the milliampere-second (mA) using fixed manual settings, during the steps not requiring high image resolution can reduce the exposure by up to 60 % [48, 56].

Also, the use of pulsed rather than continuous fluoroscopy will reduce radiation exposure (Fig. 1d), and has been successfully employed in cardiology, radiology, gastroenterology, and urology [57, 58•]. In continuous fluoroscopy, x-rays are continuously created and captured at a rate of 30 frames per second [59]. In contrast, with pulsed fluoroscopy, the operator

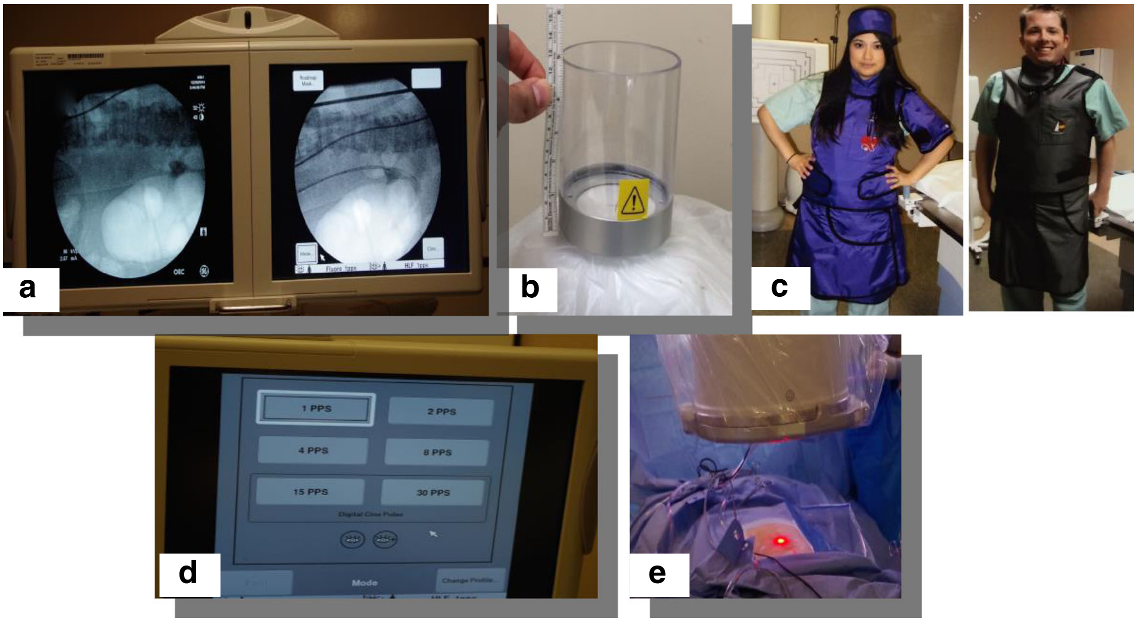

Fig. 1 **a** Use of "last image hold" during PCNL allowing for intraoperative interpretation using a saved image. **b** A 4.5-in. C-arm spacer in place to keep patient a safe distance from fluoroscopy source. C-arm should never be used without this spacer in place. **c** Modern day x-ray protective gear, including the kilt and tunic, which distributes the weight to the hips and shoulders to improve ergonomics. **d** C-arm set on pulsed fluoroscopy at 1 pulse per second for tasks that do not require high image resolution. **e** Laser-guided C-arm allows for precise positioning without the use of fluoroscopy

can reduce the number of frames per second. This pulsed image is choppier and has lower resolution (in proportion to the decrease in pulse number), but works well for many portions of endoscopy. Exceptions may include nephrostomy tube insertion, getting a wire past an obstructing stone or stricture, and looking for small residual stone fragments. Use of pulsed fluoroscopy at 4 frames/s reduced fluoroscopy time by 60–65 % compared to standard fluoroscopy [58•]. Pulsed fluoroscopy at 1 pulse per second reduced fluoroscopy time by 76 % and radiation dose by 64 % [60].

Most of the previously discussed techniques for reducing radiation exposure during fluoroscopy are equally applicable to all surgical treatments of stone disease, including ureteroscopy, percutaneous nephrolithotomy, and to some extent extracorporeal shock wave lithotripsy. However, there are unique issues associated with each of these procedures that can facilitate the reduction of intraoperative radiation, and this warrants further discussion.

Reducing Radiation During Ureteroscopy

In attempts to reduce overall fluoroscopy, we have reported and implemented protocols to reduce radiation during both ureteroscopy and ureteral stent placement [61, 62] (Table 2). The optimal strategy for reduction of radiation exposure in the operating room involves integrating many of the previously described measures into a combined protocol. By substituting tactile and external visual cues for fluoroscopy, using a laser-guided C-arm (Fig. 1e) for positioning, and an experienced C-arm technician able to provide fixed and intentionally lowered kVp and mA levels, we reduced fluoroscopy time during ureteroscopy by 82 % with no difference in operative time, complications, or stone-free rates [61, 62].

In 2010, using cadavers, we measured the organ specific radiation exposures during 145 s of fluoroscopy for a simulated left ureteroscopy. The posterior skin received 10.5 mGy, while there was 3.5 mGy to the left kidney, 2.7 mGy to the left ureter, 3.4 mGy to the left ovary, and 2.7 mGy to the left testicle [63]. Lipkin, using a validated model and data on non-obese males, found that during ureteroscopy using fluoroscopy reduction techniques, the mean fluoroscopy time was 47 s, and the patient skin entrance dose was 0.33 mGy per second, with a median effective dose of 1.13 mSv [46].

Ultrasound guidance for ureteroscopy has also been reported [64•, 65, 66]. In 2014, Deters and associates reported that US-guided ureteroscopy allowed confirmation of guidewire and stent location, and had similar outcomes compared to fluoroscopic guided ureteroscopy in a randomized trial of ureteral stones $\leq$8 mm [64•]. The limitations of this approach are that not all urologists are facile with US, and this technique is more challenging in obese patients.

There have been four studies describing a fluoroless ureteroscopy technique that used no other form of image guidance (like US) for ureteroscopy [67•, 68, 69, 70•]. Mandhani and colleagues reported on distal ureteral stones treated without the use of fluoroscopy in 99 out of 110 patients [68]. Tepeler and colleagues reported ureteroscopy with no

Table 2 Techniques to reduce intraoperative radiation exposure and fluoroscopy time during ureteroscopy and stent placement [62]

Typical intraoperative techniques	Fluoroscopy reduction protocol
Randomly assigned fluoroscopy technician	Use of a designated fluoroscopy technician
Reviewing of imaging without assessment of stone location with regard to bony landmarks	Detailed imaging review prior to beginning surgery, identification of stone location, level of stone location compared to bony landmarks
Fluoroscopic confirmation of stone location	Image present on intraoperative high-definition monitors for surgeon referral
Estimation of C-arm positioning with regard to the kidney and bladder	Use of a laser-guided C-arm
Retrograde pyelogram looking for filling defects in the ureter	Visual confirmation of stone location with ureteroscopy and direct assessment of ureteral pathology
Continuous fluoroscopy mode during wire, stent, and scope positioning	Single pulse fluoroscopy used only to confirm wire, stent, and scope positioning reliance upon visual and tactile cues
C-arm radiation source used close to the patient's body to provide magnified images	C-arm radiation source kept as far away from patient as possible to provide necessary level of anatomic detail for task being performed
C-arm operated in automatic exposure control setting where C-arm automatically increases exposure to provide optimal quality	C-arm operated in fixed manual setting where kVp and mAs are used at intentionally lowered setting to provide just enough resolution for task at hand
Full field beam is used with the C-arm	C-arm beam is collimated to only the region of interest
Fluoroscopic guidance to confirm placement of guidewire and stent	Visual and tactile cues for guidewire and stent placement
Fluoroscopic confirmation of stent bladder curl	Cystoscopic visual confirmation of appropriate stent bladder curl

fluoroscopy in 86 patients (92 % of their cohort), but obtained a KUB with 1.1 mSv on the first day postoperatively [69]. Hsi et al. reported a fluoroless ureteroscopy technique, but used two taps of fluoroscopy to confirm stent placement (median effective dose=0.05 mSv) [69, 70•].

In 2014, we reported our technique for fluoroless ureteroscopy [67•] (Video 1a and 1b). We begin by placing the patient into lithotomy position using Yellowfin Stirrups (Allen Medical, Acton, MA). A 0.038 angle-tipped Glidewire (Terumo Medical, Irvine, CA) is then placed into the ureter through a 6 Fr endhole catheter (Cook Urologic, Bloomington, IN) (Video 1a), and using tactile feedback, is manipulated past the resistance of the stone and into the kidney. When the wire is appropriately positioned in the kidney, the external end of the wire will be within 10 cm of the tip of the stirrup regardless of the patient height (Video 1a). Next, the open-ended catheter is advanced 1–2 cm past the stone (resistance of the catheter with the stone will be felt if this is a ureteral stone) and the Glidewire is converted to a standard guidewire. If a previous stent was in place, this wire is placed alongside the stent prior to stent removal. With distal ureteral stones, the standard 0.038 guidewire is left as a safety wire, and the semi-rigid ureteroscope is inserted under direct vision to the level of the stone. The stone is then fragmented in a conventional fashion using the holmium laser. During flexible ureteroscopy, a 10 Fr dual lumen catheter (Cook Urologic, Bloomington, IN) is used to gently stretch the ureteral orifice (Video 1a), and the Glidewire is again placed into the kidney. Using the endhole catheter, this wire is converted to a double floppy superstiff guidewire (Boston Scientific, Marlborough, MA). The bladder is emptied, and the flexible ureteroscope is advanced using tactile feedback until the ureteral orifice has been passed. The ureteroscope is then advanced under direct vision to the location of the stone, and lithotripsy is performed in a conventional manner (Video 1b).

Stents are routinely placed following ureteroscopy using a previously published technique [61] (Video 2). The ureteral length is measured by placing the tip of the ureteroscope in the ureteropelvic junction (UPJ) and marking the external surface of the ureteroscope at the meatus using a paper tape (in males, the penis is placed upon stretch for this measurement). The ureteroscope is then backed down the ureter ensuring complete stone removal, and the ureterovesicular junction (UVJ) is similarly marked on the external surface of the ureteroscope. The distance between the two markers is the ureteral length. The JJ stent is then inserted to this measured distance and the wire is pulled back 15 cm. The stent is then advanced until the distal end of the JJ stent is 1.5 cm below the bladder neck and the wire is removed (Video 2). Many times, this entire ureteroscopy and stent placement is performed with no fluoroscopy. However, if at any point during the procedure excessive resistance is encountered during guidewire or ureteroscope insertion, if wire lengths are not appropriate following placement, or if a tightly impacted stone is not amendable to passing the guidewire, fluoroscopy can be employed using the fluoroscopy reduction techniques discussed above.

Reducing Radiation During Percutaneous Nephrolithotomy

Since its introduction in the 1970s [71], percutaneous nephrolithotomy has evolved into the optimal treatment for most large and staghorn renal calculi [72]. Currently, the bull's eye and triangulation techniques require fluoroscopy for needle placement, track dilation, and access sheath positioning [73]. Studies have reported a mean effective dose for PCNL of 8.66 mSv, with larger BMI (greater than 40 kg/m^2) patients, those with multiple access tracts, and large stone burden at risk for higher levels of radiation exposure [74•, 75]. In fact, patients undergoing PCNL may be exposed to radiation doses similar to a non-contrast CT of the abdomen or pelvis [74•]. Subsequently, if a patient were to receive a single conventional preoperative CT, fluoroscopy during a PCNL, and a single follow-up conventional CT imaging study, they would potentially receive the same level of radiation as the 50th percentile dose of victims of Hiroshima and Nagasaki [7, 74•].

There are some maneuvers that have been employed to reduce intraoperative radiation exposure that are unique to PCNL. Our group previously described a protocol that reduced fluoroscopy time during PCNL by 80.9 %. Key steps in this protocol include fixed, lowered mAs and kVp, a laser-guided C-arm combined with an experienced fluoroscopy technician, and the fluoroscopy set at a single pulse per second [76••]. Other authors have described using air instead of contrast during pyelography, demonstrating a 50 % reduction in radiation exposure [74•, 77]. When using denser contrast, the automatic exposure control of the C-arm automatically increases the exposure as it attempts to maintain image quality [74•].

Intraoperative ultrasound has also been described as an alternative for some of the steps routinely requiring fluoroscopy during PCNL. Multiple studies have demonstrated the feasibility of utilizing ultrasound as an imaging modality during PCNL, operating on mean stone burdens ranging from 2–6 cm, producing a 63 % to 100 % stone-free rate [78–82]. Limitations of using ultrasound as the sole technique for access include the limited use in obese patients, those with full staghorn calculi, and those lacking hydronephrosis, due to reduced visibility.

Other authors have described the use of retrograde ureteroscopy to identify the optimal calyx for access, with fluoroscopy utilized to complete the access process [83]. To expand on this technique, our group has begun to use ultrasound guidance in combination with direct ureteroscopic visualization in order to obtain renal access and for completion of PCNL. All steps, including tract dilation, stent placement, nephrostomy tube placement, and renal mapping are performed using direct endoscopic visualization instead of fluoroscopy. This technique has shown promising results, even in complex full staghorn stone burdens. Using this technique, we have reduced the mean fluoroscopy access time to 4.6 s, and the mean total surgical fluoroscopic time to 10.6 s. When comparing these times to our use of the standard bulls-eye technique, we have been able to reduce total fluoroscopic time by over 800 s, and fluoroscopy time for percutaneous access by over 99 % [84].

Reducing Radiation During Shock Wave Lithotripsy

Unlike ureteroscopy and PCNL, where direct visualization, tactile and external visual cues are useful, SWL relies completely upon fluoroscopic visualization for targeting of stones in most machines. In fact, it was been previously reported that longer fluoroscopy times correlate with higher success rates [85]. Fluoroscopy times are routinely 2.7 to 4.1 min, with the average number of spot films as 6.5 to 26 [86, 87]. The average reported skin radiation exposure during SWL is 100 mSv [87–89]. Studies have compared effective radiation dose (ERD) between patients undergoing SWL with those treated ureteroscopically. In multivariate analyses, body mass index and stone size predicted a higher ERD with SWL (7.23 mSv) compared to URS (6.00 mSv) for kidney stones but not for ureteral stones (7.23 vs. 6.07 mSv) [90]. However, the radiation exposures were quite high in both groups. The key technical factors that influence radiation exposure during SWL are operator training (of both the surgeon and fluoroscopy technician), experience, familiarity with radiation physics, and control of gantry movement [87].

One alternative to dramatically reduce radiation exposure during SWL is the use of US guidance for stone targeting. Abid and colleagues compared standard SWL with fluoroscopy to the use of 3D imaging Visio-Track system. Based on their study, they reported a reduction in fluoroscopy time of 117 s [91].

Other studies have been performed comparing shock wave lithotripsy, retrograde intrarenal surgery, and percutaneous nephrolithotomy for 1–2 cm radiolucent renal calculi [92, 93]. In both of these studies, ultrasound was used to target the stone during SWL. However, despite no fluoroscopy with US-guided SWL, stone-free rates varied between 37 % and 66.5 % [92, 93] calling into question the effectiveness of fluoroless SWL.

Follow-up Imaging After Stone Treatment

Kidney and ureteral stone patients also receive ionizing radiation during the follow-up period. In the postoperative period, a combination of KUB for residual stones and a renal ultrasound to detect possible silent hydronephrosis may be adequate following ureteroscopy or SWL, as the combination of these modalities has a sensitivity of 97.9 % and positive predictive value of 97.9 % [94, 95]. In young patients with solitary stones, a renal ultrasound alone may be an adequate follow-up. However, during instances where stone free is essential, for example, following PCNL for an infectious stone, a low-dose CT will provide higher sensitivity and detect smaller residual stones.

Conclusion

Conventional techniques used to image and treat stones result in significant radiation exposure to the patient and the operative team. Surgeons should use alternative imaging when possible, space out imaging, and avoid imaging if it is not required. When CT imaging is required, low and ultra low-dose CT provide high sensitivity and specificity during the initial evaluation and follow-up of stone patients with dramatic reductions in radiation exposure. Intraoperatively, many techniques are available to reduce the radiation exposure associated with fluoroscopy that have no effect upon stone-free rates or treatment outcomes. Surgeons should continue to strive to reduce radiation exposure to patients in accordance with the ALARA principle.

Compliance with Ethics Guidelines

Conflict of Interest Javier L. Arenas and D. Duane Baldwin each declare no potential conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- • Of importance
- •• Of major importance

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