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Review

Radiation protection measures during endourological therapies

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Abstract *Objective:* The objective of this narrative review was to search the existing literature for studies reporting measures to minimize radiation use during endoscopic management of stone disease and present ways of reducing the exposure of both patients and operating room staff.

Methods: A literature review in PubMed was performed to identify studies describing protocols or measures to reduce radiation received during endourological procedures from January 1970 to August 2022. Eligible studies were those that reported outcomes for ureteroscopy or

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As low as reasonably achievable

percutaneous nephrolithotripsy regarding measures to minimize radiation doses used intraoperatively, performed either in real-life theatres or using phantoms. Both comparative and non-comparative studies were deemed eligible.

Results: Protection can be achieved initially at the level of diagnosis and follow-up of patients, which should be done following an algorithm and choice of more conservative imaging methods. Certain protocols, which follow principles for minimized fluoroscopy use should be implemented and urologists as well as operating room staff should be continuously trained regarding radiation damage and protection measures. Wearing protective lead equipment remains a cornerstone for personnel protection, while configuration of the operating room and adjusting X-ray machine settings can also significantly reduce radiation energy.

Conclusion: There are specific measures, which can be implemented to reduce radiation exposure. These include avoiding excessive use of computed tomography scans and X-rays during diagnosis and follow-up of urolithiasis patients. Intraoperative protocols with minimal fluoroscopy use can be employed. Staff training regarding dangers of radiation plays also a major role. Use and maintenance of protective equipment and setting up the operating room properly also serve towards this goal. Machine settings can be customized appropriately and finally continuously monitoring of exposure with dosimeters can be adopted.

1. Introduction

Urolithiasis is a common clinical condition with estimated prevalence of 10.6% in males and 7.1% in females [1]. Patients who experience stone-related episodes are exposed to radiation at all steps during their management.

Computed tomography (CT) imaging is the gold standard for diagnosing a stone within the urinary tract and planning the following surgical management [2]. X-ray and ultrasound are other commonly used imaging diagnostic modalities. The dose received from a CT scan is 10 milliSieverts (mSv), from a low-dose CT scan 3 mSv, and from X-ray of kidneys-ureter-bladder 0.7 mSv [3]. Studies comparing low-dose with standard CT protocols, reported excellent sensitivity and specificity for patients with body mass index (BMI) less than 30 kg/m^2; therefore, these protocols are mainly used today [2,4].

Minimally invasive procedures such as shockwave lithotripsy, ureterorenoscopy (URS), retrograde intrarenal surgery (RIRS), and percutaneous nephrolithotripsy (PCNL) have almost totally displaced open surgery for treatment of urinary tract stones. Radiation is linked inseparably to the guidance and orientation of urologists in the operating room, contributing to radiation exposure both to patients and operating staff [5,6].

In addition to diagnosis and management, follow-up of patients with urolithiasis commonly incurs considerable amounts of radiation for patients. Fahmy et al. [7] reported the mean effective radiation exposure (MERE) dose during the first year of follow-up in urolithiasis patients was 29.29 mSv, while in the second year, MERE dose declined to 8.04 mSv with no patient exceeding the annual limit. Similarly, Ferrandino et al. [8] found that one out of five patients surpassed the 50 mSv threshold, with MERE dose equal to 29.7 mSv. Interestingly, patients underwent a mean of 1.2 X-rays, 1.7 CT scans, and one intravenous pyelography during first year of follow-up after an acute stone episode [8]. Recognizing the necessity of an established follow-up pattern, to help minimizing radiation burden, European Association of Urology guideline panel on urolithiasis, performed a comprehensive literature review and proposed a specific imaging follow-up plan, regarding timing of patient discharge after surgical or medical treatment and a consensus statement on how to follow up patients [9–13].

Ionizing radiation generates high energy particles, which emit electrons inducing DNA alterations and subsequently cellular damage. The effects on tissue are either deterministic (occurring when a certain threshold is overpassed) or stochastic (occurring with gradual accumulative effect of lower doses) [14]. Deterministic effects, such as cataracts, skin erythema or burns, thyroid dysfunction, and acute radiation syndrome are encountered in cases with acute, massive exposure to radiation and thus do not present a significant risk to urologists or patients. However, chronic exposure of human DNA to radiation leads to mutagenesis and there is a certain risk of developing malignancy [14]. It is often argued that no safe lower limit exists, below which no risk exists for humans, since there is always a danger of future carcinogenesis [15]. Scientists reported that every year, 0.9% of neoplasms in the United States and 3% in Japan are linked to radiation exposure for diagnostic and therapeutic reasons [16].

These observations led the International Commission on Radiation Protection to recommend an annual occupational threshold of 50 mSv to the whole body, less than 500 mSv to the extremities, and less than 20 mSv to the eyes (20 mSv in a single year and 100 mSv in five consecutive years) [17]. Adjunctively, the International Commission on Radiological Protection (ICRP) proposed the "as low as reasonably achievable" (ALARA) principle to minimize the damaging effects of radiation [17]. It is vital for urologists to remember that ALARA should apply during the entire process of patient management (diagnosis, intraoperation, and follow-up) [18]. To understand radiation-related information, surgeons should familiarize themselves with some of the key definitions. Gray (Gy) unit is the radiation required to apply 1 J energy per kilogram of target matter [19]. The absorbed dose is the quantity absorbed by the target and is calculated from the air-kerma, which is a metric provided along with fluoroscopy time from the machine (air-kerma and absorbed dose are measured in Gy) [19—21]. The equivalent dose measures tissue-specific differences in absorption and is measured in Sieverts (Sv), while the effective dose is the sum of equivalent doses [19—21]. Effective and equivalent doses are the most clinically significant values to be measured [21].

The objective of this narrative review was to search the existing literature for studies reporting measures to minimize radiation use during endoscopic management of stone disease and present ways of reducing the exposure of both patients and operating room staff.

2. Methods

A literature review in PubMed was performed to identify studies describing protocols or measures to reduce radiation received during endourological procedures from January 1970 to August 2022. The search algorithm used was the following: (radiation) AND (endourology OR PCNL OR "percutaneous nephrolithotripsy" OR URS OR ureteroscopy OR ureterorenoscopy OR "endoscopic surgery").

Eligible studies were those that reported outcomes for ureteroscopy or PCNL regarding measures to minimize radiation doses used intraoperatively, performed either in real-life theatres or using phantoms. Both comparative and non-comparative studies were deemed eligible.

3. Results

A total of 9070 abstracts were initially identified using the search algorithm. After abstract and title screening, we excluded 8845 abstracts, and 225 records were evaluated for eligibility after reading the full-text. Finally, a total of 83 manuscripts were deemed eligible for inclusion.

In detail, 11 studies were about radiation exposure and associated harms [3—8,10,11,14—16]; 19 studies analyzed data on flexible or semirigid URS [18,19,21—37]; nine studies assessed factors that affect radiation exposure during PCNL [38—46]; 21 studies evaluated several methods of renal puncture and their effect on radiation [47—67]; two studies reported outcomes on tract dilation [68,69] and another two protocols for reduction of radiation during the whole procedure [70,71]. Regarding general measures that should be implemented to reduce radiation exposure, one study highlighted the need for monitoring of exposure [72]; five evaluated the role of surgeon experience [73—77]; six studies compared pulsed with continuous fluoroscopy [78—83]; two analyzed the role of over- or under-the-couch machines [84,85]; two assessed the differences observed according to who controls the fluoroscopy pedal [86,87]; and finally, five reported the role of lead protective equipment [77,88—91].

The most important proposed measures that should be implemented according to literature review are summarized in Table 1.

4. Discussion

4.1. URS

URS constitutes one of the commonest endourological procedures performed either with semirigid or flexible instruments. URS is mostly performed under fluoroscopic guidance even from experienced endourologists to ensure the best clinical outcome both in terms of stone burden clearance and minimizing complications [2,22]. The radiation exposure derived from C-arm use during URS depends on machine settings (kVp, milliampere [mA], collimation, pulse rate, type of C-arm used, focus of the beam, and fluoroscopic time), patient characteristics (anatomical abnormalities, existence of ureteric strictures, stone location, and burden, BMI), use of protective equipment from operating room staff and finally on surgeon's practice (experience, knowledge about radiation related metrics, and specific steps followed during surgery) [23]. Several reports quantify the radiation received per patient between 2.5 mSv and 100 mSv [24,25]. RIRS for treating renal stones is also associated with high radiation doses, since it is estimated that may require up to 314 s of fluoroscopy use, especially if X-ray is used to place a ureteral access sheath (UAS) or to navigate flexible ureteroscope within the calyceal system [26].

Even though fluoroscopy is considered essential for URS and RIRS from the majority of urologists, there are several studies in literature supporting the use of ultra-low dose or totally fluoroless URS. Greene et al. [27] followed a protocol of reduced dose URS, by adopting specific intraoperative principles such as estimating stone location with the C-arm laser, placing the guidewires and double-J stents using visual and tactile information, detailed preoperative study of patient imaging, timely activation of C-arm with patient respiration cycle, cooperation with a dedicated technician, use of pulsed instead of continuous fluoroscopy, and visual recognition of stone location and double-J stent bladder curl. By this way, they achieved an 82% reduction of total fluoroscopy time (from 86.1 s to 15.5 s) without noticing significant differences for stone-free rates (SFRs), complications, operative time, or auxiliary procedures [27]. Danilovic et al. [28] performed a comparative study using standard or low-dose fluoroscopy by adjusting the mAs to 1/4 of standard dose for ureteral stone treatment. By making this simple technical alteration to machine settings, authors reported that both cumulative radiation emitted by the C-arm was reduced (3.6 mGy *vs.* 16.2 mGy, $p=0.0001$) and dose area product was minimized (0.23 mcGy/cm^2 *vs.* 1.15 mcGy/cm^2, $p=0.02$), while fluoroscopic time, SFRs, complications, or ureteral stricture rates did not differ significantly [28]. Importantly, although reducing mAs impairs image clarity, no surgeon asked for an increase in fluoroscopy dose [28]. The natural sequence of the encouraging results from low-dose fluoroscopy was the adoption of zero-dose fluoroscopy. Tepeler et al. [29]

Table 1 Summary of measures to be implemented in order to reduce radiation exposure.

Setting	Specific steps to follow
Diagnosis and follow-up of urolithiasis patients	- Use of low-dose CT protocols, especially for patients with BMI of <30 kg/m^2 - Follow-up patients according to their risk for recurrence and residual stone burden; consider European Association of Urology follow-up algorithm
Ureteroscopy	- Estimate stone and kidney location by C-arm laser and avoid use of fluoroscopy - Place guidewires and double-J stents using anatomic landmarks and tactile feedback - Use hydrophilic, soft-tip guidewires - Synchronize use of fluoroscopy with patient respiration - Assess preoperative imaging in detail to delineate patient anatomy and stone characteristics - Choose ureteric access sheath according to patient height - Confirm guidewire placement using a semirigid ureteroscope in case of doubt - Assess stone clearance visually when possible
Percutaneous nephrolithotripsy	- Estimate stone and kidney location by C-arm laser and avoid use of fluoroscopy - Use hydrophilic, soft-tip guidewires - Synchronize use of fluoroscopy with patient respiration - Assess preoperative imaging in detail to delineate patient anatomy and stone characteristics - Use ultrasound for renal puncture either as the only guidance or at least adjunctively to X-ray - Take advantage of direct visual feedback with flexible ureteroscope in cases of ECIRS to guide renal puncture with minimal fluoroscopy - Consider use of balloon instead of serial dilators to minimize fluoroscopy time
Setting of operating room	- Monitor use of fluoroscopy - Use alarms - Use protective equipment (aprons, thyroid shields, glasses) - Ensure proper protective equipment maintenance and storage - Cooperate with technician if possible - Ensure proper positioning of patient and avoid interference between target area and X-ray beam - Staff should stand as far as possible from X-ray source
X-ray machine settings	- Use pulsed instead of continuous fluoroscopy - Make use of last-image hold option - Avoid using pre-established settings of mAs and kVps and lower the settings, especially in patients with normal BMI - Use collimation to minimize scattered energy - Use image magnification when suitable

CT, computed tomography; BMI, body-mass index; ECIRS, endoscopic combined intrarenal surgery.

managed to successfully perform 92.4% of their URS without using fluoroscopy. Next, Hsi and Harper [30] described in detail their steps to succeed in fluoroless URS with both rigid and flexible ureteroscopes. In short, detailed preoperative analysis of imaging studies, use of C-arm laser, placement of guidewire, and UAS by tactile and visual feedback or through previously inserted double-J stent and empirical assessment of guidewire location by comparing the length out of the body, which should be no longer than contralateral patient foot, are some essential steps [30]. In case of narrow ureteric lumen, it is advised to use a second guidewire and place an UAS after visual inspection of ureter using the scope [30]. Finally, authors after guiding the stent over the guidewire up to 20-cm mark, used the pedal instantly to confirm proper placement and inspected the bladder curl visually [30]. In this study, authors did not exclude patients with impacted stones, tortuous or stenotic ureters, or anatomic alterations, and yet achieved to perform fluoroless URS (excluding single pedal tap during stent placement) for 75% of patients, while the median air-kerma dose was 0.6 mGy, mean fluoroscopy time 2 s, and median effective dose 0.05 mSv [30]. Presetting of machine to adjust for voltage and current settings for low-dose exposure, and utilization of collimation to minimize scattered energy and pulsed instead of continuous mode certainly explain the minimal amount of radiation [30]. Olgin et al. [31] also compared fluoroless to conventional URS and concluded that SFRs, operating room time, and complication rates are similar, even though fluoroless URS group had a larger stone burden. Of course, there is always the potential to perform URS using ultrasound guidance intraoperatively as nicely demonstrated by Deters et al. [32], but this necessitates a high level of expertise, trained personnel, and additional operating room equipment.

Following the encouraging results of fluoroless and ultra-low dose URS, recent attempts have been described for performing flexible RIRS (flRIRS) with minimal or no radiation. Hein et al. [33] compared conventional to low-dose flRIRS, where radiation was used mainly for stent insertion or in cases of difficult calyx localization. Proper UAS was tailored to patient height, while retrograde pyelogram was omitted, and insertion of guidewires was performed visually using the semirigid ureteroscope [33]. Authors reported a massive reduction in fluoroscopic time (167.7 s *vs.* 7.4 s, $p<0.001$) and dose area product (318.4 cGy/cm^2 *vs.* 6.4 cGy/cm^2, $p<0.001$), along with reduced operating room time (91 min *vs.* 65 min, $p<0.001$), without significant differences in SFRs and complications [33]. When the same principles were tested at a multicenter study, less impressive improvement was observed in reduction of radiation exposure, possibly reflecting variations among centers, although an interesting finding was that SFRs improved in the group using less fluoroscopy [34]. Similar findings have been described by Manzo et al. [18] and Kirac et al. [35]. Going one step further, Ayoub et al. [37] evaluated fluoroless technique for high burden renal or proximal ureteric stones treated with flRIRS or combined flRIRS and mini-PCNL. For gaining kidney access when desired, surgeons located the tip of flexible ureteroscope with ultrasound in the ideal calyx and during needle puncture and insertion, the flexible scope provided excellent, real-time visual assessment of proper puncture [37]. Authors reported a high SFR of 91.8% with low complication rate (3.3%), which were all minor according to Clavien-Dindo grading system [37], indicating that fluoroless technique can be safely applied to this category of patients.

All these findings are nicely summarized by Subiela et al. [36] in their systematic review and meta-analysis, where pooled analysis of 4029 patients to compare conventional and fluoroless URS, showed similar SFRs, intra- and post-operative complications, operating room time, length of stay, and need for auxiliary procedures. Some crucial steps to consider during fluoroless URS are: use of a hydrophilic, soft tip guidewire to avoid ureteral wall damage and perforation [18], and use of semirigid scope for confirming proper insertion of guidewire and to achieve ureter dilation for UAS insertion; finally, if resistance is felt during guidewire or more importantly UAS insertion, it is preferable to pull back and make a new, gentle effort or use fluoroscopy to ensure proper entrance [92]. Most studies using low-dose or no fluoroscopy, included uncomplicated patients without abnormal anatomy, impacted stones, and tortuous or stenotic ureters, where treating surgeons were highly experienced endourologists. Although this should not discourage less experienced urologists to adopt these protocols, it is always advisable to do this in a stepwise manner and always have available in the operating room, the C-arm and personal protective shielding in case fluoroscopy is needed [36].

4.2. PCNL

4.2.1. Exposure to radiation during PCNL

PCNL is the gold standard treatment for stones larger than 2 cm with high SFRs [2]. Radiation is used during multiple steps, namely insertion of ureteric catheter and guidewire for retrograde pyelogram, kidney puncture, percutaneous tract dilatation, advancement of the guidewire to the ureter, evaluation for residual fragments, and proper positioning of double-J stent and nephrostomy tube. The majority of radiation exposure occurs during kidney puncture; although ultrasound-assisted access is both well described and considered safe, the majority of urologists prefer to employ fluoroscopy (86.3% *vs.* 13.7%), according to a large multicenter study [47]. The exact amount of radiation to which operating room staff and patients are exposed to during PCNL is more difficult to quantify, compared to URS. This is explained by the existing variability in renal puncture techniques, patient characteristics and positioning, surgeon experience, number of tracts, method of dilatation, and type of shielding used, as well as machine settings. There are older reports of very high radiation amounts needed during PCNL with a mean dose of almost 4 mSv to the hands, nearly 6 mSv to fingers, and 1 mSv to eyes of the radiologist [38]. However, more recent studies report a dose of 0.56 mSv for the patient, 0.28 mSv for urologists' fingers [39], and 0.12 mSv for urologists' forehead [40]. Even lower values have been reported by Safak et al. [41], who detected mean doses of 0.026 mSv to the eyes, 0.0335 mSv to the fingers, and 0.048 mSv to the collar of urologists, while the mean total dose was 7.3 mSv for the patient and 0.0127 mSv for the surgeon. Despite existing literature discrepancies, data show a stronger and more consistent positive correlation with increased radiation exposure and higher BMI [42,43], higher stone burden or volume [42—44], non-branched and multiple stones [42], and higher number of tracts [42—44]. Lipkin et al. [45] studied organ-specific doses using an anthropometric model, set for a left and right PCNL. They set the machine at 90—91 kVp, 3.0 mAs and equivalent dose rates (mSv/s) were calculated using the organ tissue weighting factor. Based on this experiment, they calculated that for non-obese males, effective doses of 7.63 mSv for right and 8.11 mSv for left PCNL were applied, while after skin point of radiation entrance, stomach on the left and gallbladder on the right received greater amounts of radiation [45]. St-Laurent et al. [46] during another experiment using an anthropomorphic model, recorded that effective radiation doses for the surgeons were 1.3—1.5 times higher when patient was placed in the prone compared to the supine position.

4.2.2. Ultrasound use during PCNL

Ultrasound guidance during PCNL offers several advantages such as massive reduction or even elimination of radiation, recognition of anterior and posterior calyces, identification of major vessels using Doppler function, imaging of structures between skin and kidney, and depth estimation and delineation of kidney anatomy (hydronephrosis, cysts, *etc.*) and stone location [48]. Agarwal et al. [48] performed a randomized controlled trial, in which one group underwent ultrasound-guided puncture and the other, conventional fluoroscopy-guided puncture. Remaining steps were performed using fluoroscopy as needed in both groups. They concluded that time needed for proper puncture, fluoroscopic time, number of attempts for successful entrance into the desired calyx, and time for tract formation were all in favor of ultrasound-guided puncture and no differences were detected regarding SFRs, complications, bleeding, or length of hospital stays [48]. A useful tip proposed by the authors is the insertion of 2—3 mL of air through the ureteric catheter, which directs to posterior calyces in the prone position and facilitates ultrasound-guided puncture [48]. It is proposed by most experts that the steep learning curve for PCNL (>60 cases to be competent and >100 cases to achieve excellence) is explained mainly by difficulty in gaining renal access [49]. Jagtap et al. [50] took this into account and performed a randomized trial to compare safety and efficacy of gaining renal access during PCNL when performed by trainees, who used ultrasound or fluoroscopy. They found that even for non-experts, use of ultrasound during puncture decreased significantly the total fluoroscopic time (204.3 s *vs.* 239.9 s, $p=0.004$), with no difference in SFRs, operating time, complications, hemoglobin drop, pain, or hospital stay [50].

In obese patients, there are indications that despite similar fluoroscopic time with their matched non-obese individuals, the received radiation is increased due to automatic machine adjustments in order to provide good quality images [51]. For example, when doubling tissue thickness, in order to provide the same quality of images, an increase in radiation dose by 10-fold may be necessary [51]. Usawachintachit et al. [52] assessed ultrasound-guided puncture in obese patients compared to fluoroscopy and concluded that although successful puncture was less common in obese patients with ultrasound compared to normal-weighted patients (45.7% *vs.* 76.9%, $p<0.05$), radiation exposure decreased significantly for obese patients. Minimizing exposure of obese patients is quite important, since obesity leads not only to increased radiation doses due to machine automatic technical configurations, but also to increased cumulative exposure from diagnostic studies and interventions, since these patients relapse more frequently [53].

In most studies, urologists make use of ultrasound only during renal puncture due to inherent difficulties in recognizing fascial dilators. Falahatkar et al. [54] performed a randomized trial to compare completely ultrasound-guided supine PCNL to conventional supine PCNL. The authors used Amplatz sheath dilators and although they reported that the sheath was not clearly visible by ultrasound, the SFRs, complications, or length of stay did not differ between the two groups [54]. Most urologists perform renal puncture via the lower or middle pole to avoid pleural trauma. However, there are cases (*e.g.*, upper pole stones and staghorn calculi) where upper pole access is required. Sahan et al. [55] evaluated the use of ultrasound for puncturing the upper pole and found that this technique resulted in lower hemoglobin drop and less radiation time compared to a fluoroscopic technique (134.2 s vs. 82.2 s, $p=0.001$).

It is clear that ultrasound offers a safe access while reducing radiation exposure. However, there are certain aspects to consider before incorporating it into routine clinical practice. As nicely summarized by Chu et al. [56], there are two main approaches: the longitudinal and the transverse. In both techniques, a curved array transducer in 3.5—5.0 MHz range is needed, with the depth set at 8—12 cm to maximize size of kidney on the screen [56]. Settings should be set to optimize contrast between needle, stones, and renal parenchyma, while if Doppler is available it facilitates in recognition of vascular structures [56]. During the longitudinal approach, the probe is set along the kidney longitudinal axis and the needle is advanced towards the desired calyx (using a guide or free hand), after puncturing the skin in front of or behind the probe [56]. The needle should always stay in parallel with the probe and should be visualized along the whole tract [56]. Caution should be given not to push the needle through the skin in an oblique fashion, since this may hinder tract dilatation [56]. During the transverse technique, the ultrasound probe is oriented along the transverse kidney axis and needle is advanced orthogonally to probe axis [56]. The main drawback is that the probe should move back and forth continuously to locate the needle along the tract [56]. A nice tip given by authors is the potential translocation of stones from the lower pole to the renal pelvis with a puncture needle using ultrasound guidance, thus making the stone easily accessible [56].

4.2.3. Endoscopically guided PCNL

The technique of retrograde placement of nephrostomies was developed by Hunter et al. in 1983 [57], while later on Munch et al. [58] used the puncture wire to advance it though a flexible scope. Using this technique, flexible ureteroscopy is performed to recognize the suitable calyx for entry, based on preoperative imaging studies [59]. Then a specific puncture wire is advanced through the scope and then from the calyx towards skin [59]. After careful exit of the wire, a coaxial catheter is inserted over the wire and a hydrophilic guidewire is placed and procedure continues in the standard way [59]. Lantz et al. [60] assessed this technique and suggested that the mean fluoroscopic time (3.4 min) and mean effective dose for patients (2.4 mSv) were less for a conventional technique.

4.2.4. Other techniques

Technological advancements led to several innovative methods for renal puncture. Bader et al. [61] tested a needle with an incorporated optical system to visualize the entrance into the collecting system, while needle was advanced using ultrasound. Rassweiler et al. [62] described a technique where puncture was achieved using a three-dimensional reconstruction of patient anatomy on an iPad, based on preoperative imaging. Despite the short learning curve and nice anatomical visualization, this latter technique required high doses of radiation (337.5 $\mu Gy/m^2$) [62]. Ritter et al. [63] proposed a technique where a technology named Uro Dyna-CT was used to create real-time, CT-like images intraoperatively, which permitted safe renal puncture. However, Uro Dyna-CT was accompanied by radiation doses even higher than conventional fluoroscopy (5850 $\mu Gy/m^2$) [63]. Another promising category of renal puncture techniques is the use of magnetic fields created in the operating room, which guide needles with sensors to perform a safe and accurate puncture. During the puncture step, the needle is followed with ultrasound [64,65] or guided only by sensors and the position is confirmed using a ureterorenoscope [66]. Obesity and calyces occupied by large stone burden may impair successful puncture using these methods [64—66]. Finally, robotic devices (AcuBot, John Hopkins MrBot, and

PAKY-RCM) have been designed to facilitate needle guidance and avoid operator dependence [67].

4.2.5. Dilation of the tract

Besides renal puncture, fluoroscopy is also used during dilatation of the percutaneous tract. Although the location and monitoring of dilators by ultrasound is feasible, it requires certain skills and the ability to discriminate between the echogenic guidewire and non-echogenic dilators [68]. Also balloon dilators contain an echogenic tip which can be monitored [68]. Nevertheless, most urologists will probably use fluoroscopy during this step. Yildirim et al. [69] performed a comparative study to assess the dilatation using balloon dilator versus Amplatz-type dilators. They concluded that the group in which balloon dilator was used, achieved faster renal puncture (15 min *vs.* 22.6 min, $p<0.003$) and less overall fluoroscopic time (6.6 min vs. 10.4 min, $p=0.006$); therefore, the authors suggested that balloon dilators may be preferred over serial, Amplatz dilatation [69].

4.2.6. Radiation reduction protocols

As described for URS, specific protocols for reducing radiation doses have also been described for PCNL, although a totally-fluoroless PCNL is more difficult to be performed. Blair et al. [70] adopted a protocol to reduce fluoroscopy by omitting the initial fluoroscopic image, display of preoperative imaging in the OR, use of laser guidance from the C-arm machine, activating the C-arm at end-expiration, placing the guidewire using tactile feedback, lowering mAs and kVp of the machine, selecting single pulse instead of continuous fluoroscopy, and cooperating with a trained technician. The authors observed a dramatic fluoroscopic time reduction after adopting the protocol (175.6 s *vs.* 33.7 s, $p<0.001$) with no change in complications or SFRs [70]. Sourial et al. [71] reported a drop in fluoroscopic time by 75% when a similar principles were applied.

4.3. Effect of monitoring, training, and experience

Existing studies have highlighted that when urologists are aware that fluoroscopy use is being monitored, they are more likely to reduce it. This change in behavior is considered a result of the Hawthorne effect. Another explanation is that they become more experienced over time and though educational courses, if available. Ngo et al. [72] reported a 24% reduced fluoroscopic time in URS after monitoring experienced surgeons, while Ritter et al. [73] found a quite similar 20% reduction. Weld et al. [74] conducted a study in which residents were trained in a program called SMART (safety, minimization, and awareness training) and tested their practice before and after this educational activity. Authors observed that after residents had been trained, they achieved a 56% reduction in fluoroscopy time. When matched with another group of residents regarding surgical experience, but untrained for radiation reduction techniques, 42% reduction was reported [74]. The same group compared the use of fluoroscopy according to resident experience for conducting uncomplicated URS and concluded that by the end of the first year of training and 50 cases per resident, fluoroscopy time reduced by 54%, while at the end of second year by 79% after 100 cases per resident, reaching a mean of 29 s per case [75]. Sfoungaristos et al. [76] evaluated the effect of higher levels of training by comparing fluoroscopy time during URS performed by fellows and their trainers. They concluded that the decrease in fluoroscopy use between the 1st and 2nd year reached 50.7% [76]. Despite the profound positive effect of training on reducing radiation exposure, during a recent survey, Tzelves et al. [77] found that only 25% of endourologists were trained on radiation protection.

4.4. Effect of machine settings

Most fluoroscopic machines in the past used to run under continuous mode, where the unit produced 30 images per second (frames per second [fps]), resulting in a movie-like image, while the pulsed mode results in as low as 1 pulse per second [78]. Pulsed modes of newer machines are controlled in the X-ray tube rather than energy generator and the required set amount of radiation is achieved more quickly, thus reducing fluoroscopy time [78—80]. Another way of reducing radiation amount in pulsed mode, is the minimization of blooming effect of the image intensifier, which occurs in the continuous mode [79,81]. Blooming is a short duration of overexposure which occurs when moving the image intensifier from a dense area (bones) to a less dense area (renal parenchyma) [79]. The first clinical testing of pulsed fluoroscopy was performed by radiologists blinded to 15 fps, 7.5 fps, and 3.75 fps, and did not report important defects of image quality in gastrointestinal images, voiding cystourethrography, or placement of percutaneous nephrostomy [79]. Elkoushy et al. [82] compared 30 fps to 4 fps in URS and PCNL, reporting that fluoroscopic time was reduced in both procedures (URS: 109.1 s *vs.* 44.1 s, $p<0.001$; PCNL: 341.1 s *vs.* 121.5 s, $p<0.001$) and although quality of image was worse in pulsed fluoroscopy, no effect in success rates was observed. Smith et al. [78] compared continuous with pulsed fluoroscopy at 1 fps in URS and revealed a 64% reduced radiation dose and 76% decreased fluoroscopy time. They also showed that 1 fps produced images of adequate quality to locate stones and guidewire [78]. Durutovic et al. [83] compared fluoroscopy produced at 30 fps to 2 fps during PCNL and found a significant reduction of fluoroscopic time (155.4 s *vs.* 76.8 s, $p<0.001$).

4.5. C-arm choice, setting of operating room, and pedal activation

Fluoroscopy machines can be categorized as over- or under-the-table, meaning the X-ray tube is located over- or under-the-table, respectively, while the image intensifier lies on the opposite side. Ritter et al. [84] evaluated the radiation exposure to the urologists when using an over-the-table machine during PCNL, URS, and insertion or change of double-J stents. The machine used continuous fluoroscopy, while settings were changed automatically to adjust brightness and image quality [84]. Authors found that during PCNL, the surgeon was exposed to higher radiation doses compared with those reported in the literature, especially among the fingers [84]. This observation is reasonable, since surgeon exposure occurs mainly due to scattered radiation, which is greater in over-the-table devices. In a more recent study, Cabrera et al. [85] used an anthropomorphic model to measure doses of radiation during a URS-like setting using an over- or under-the-table machine. They measured lower doses for all organs using the under-the-table C-arm [85]. In detail, skin received the highest doses in general (0.329 mGy *vs.* 0.007 mGy), while gallbladder and stomach came first from visceral organs [85]. The total effective dose was also lower with the under-the-table at 0.0029 mSv/s compared to 0.0240 mSv/s with the over-the-table device [85]. Therefore, use of under-the-table machines is advised, ideally those which permit alteration of settings like mAs, kVps, and fps (pulsed mode). Image collimators are encouraged since unnecessary exposure of areas outside the area of interest is avoided, while at the same time image quality is improved from reduced scattered energy. Overmagnification of the image is also advised since radiation dose is increased.

Several steps can also be considered to minimize radiation dose including operating room setup and configuration. Patient positioning is very important, since interference of objects between the patient body and X-ray beam, results in considerable increase of radiation. This is especially important in case metallic objects, *e.g.*, parts of an improper, non-endourological surgical table are used or when metallic parts of the table are between patient and beam due to false patient positioning. In addition, the X-ray tube should be located as near as possible to the anatomical area of interest in order to minimize scattered radiation and energy required. At the same time, operating room staff should stand far from radiation beam since the inverse square law applies. This means that for every doubling of the distance from radiation beam, the exposure is lowered 4-fold. Last-image hold is another valuable functionality of newer devices, which aids in avoiding unnecessary image repetition. As described before, monitoring of technique and use of fluoroscopy results in 20%—24% reduction of its use [72,73], and thus time alarms and continuous recording with thermoluminescent dosimeters are very useful.

Debate exists regarding the most optimal operating room staff member to control the fluoroscopy device. Although there are studies reporting no difference in fluoroscopy time [86] and others favoring control from the urologist [87], we believe this depends on local circumstances, since the availability of a trained and dedicated technician may prove beneficial.

4.6. Lead shielding equipment

The importance of personal lead shielding to reduce radiation doses is unquestionable. Lead aprons protecting the chest and pelvis reduce gonads' dose by 80% and bone marrow by 90%—95.5%, thyroid shields reduce doses 100-fold, lead-lined glasses 10-fold, and lead-lined gloves 7%—50% [88]. They should consist of at least 0.5 mm lead layer, must be inspected at least annually, and should be hung after use and not folded due to potential damage of protective layer. Monitors for radiation exposure should be worn over the lead at the level of the neck and under lead at surgeon's waist. Despite the high level of protection, a survey performed by Tzelves et al. [77] indicated that aprons or thyroid shields are not used by all endourologists (89.6% and 84.4%, respectively). Googles were used by 14.7% and gloves by 8.1% of responders [77]. Eye lens is considered one of the most sensitive organs to radiation exposure with recommended annual doses less than 20 mSv [17]. Measured eye lens dose varies according to procedure performed, with 2.97—100 μSv during ureteroscopy and 0.04—1600 μSv during PCNL [89]. Considering the above, it is highly advised that endourologists adapt the daily use of protective glasses in the operating room.

In addition to personal protective equipment, several innovative lead shields have been described. Yang et al. [90] tested a new shielding during PCNL, reporting 96.1% reduction at 25 cm and 71.2% reduction at 50 cm distance from X-ray source. The shield was made of 0.5 mm lead and was easily applied to operating table set up without compromising surgeon movements [90]. Inoue et al. [91] designed a study where an anthropometric model was used to test an operating room configuration with the use of lead curtain at the operating table during URS. Then they tested the new shield in a comparative study of patients undergoing URS with or without the shield [91]. They concluded that the use of shield resulted in 80% less scattered radiation and during the comparative trial, urologists were protected by 74% for the effective dose, 62.1% at their neck, 86.1% at their waist, and 100% at the level of their chest [91].

5. Conclusion

Radiation exposure entails certain health dangers even if low doses accumulate over a long period of time. There are specific measures, which can be implemented to reduce doses. This includes following a conservative use of imaging when diagnosing and following up these patients and avoiding excessive use of CT scans and X-rays. Intraoperative protocols with minimal fluoroscopy use can be employed. Staff training regarding dangers of radiation and ways to be protected plays also a major role. Wearing protective equipment, preserving it in a proper manner, and setting up the operating room properly also serve towards this goal. Machine settings can be customized in an appropriate configuration and finally continuously monitoring of exposure with dosimeters can be adopted.

Author contributions

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Conflicts of interest

Andreas Skolarikos is the Chairman, Bhaskar Somani a Member, and Lazaros Tzelves an associate member of the EAU Urolithiasis Guideline Panel; Lazaros Tzelves, Ioannis Mykoniatis, Patrick Juliebø-Jones, Belthangady M. Zeeshan Hameed, and Amelia Pietropaolo are members of the EAU Young Academic Urologists, Urolithiasis & Endourology Working Party. The other authors declare no conflict of interest.

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