Asian Journal of Urology (2020) 7, 10—17

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/ajur

Review

Percutaneous kidney stone surgery and radiation exposure: A review

Bohdan Baralo [a], Patrick Samson [b,*], David Hoenig [b], Arthur Smith [b]

[a] Urology Department, National Pirogov Memorial Medical University, Vinnytsya, Ukraine
[b] Department of Urology, Smith Institute for Urology, Northwell Health, New Hyde Park, NY, USA

Received 1 March 2018; received in revised form 6 August 2018; accepted 8 October 2018
Available online 23 May 2019

KEYWORDS
PCNL;
Urolithiasis;
Reduction of radiation exposure;
Percutaneous kidney access;
Diagnostic imaging;
Training

Abstract During the past 3 decades, radiation exposure (RE) has increased drastically among patients undergoing percutaneous nephrolithotomy (PCNL), thus potentially causing new cases of cancer each year. The effective dose received by patients comes from pre- and post-operative computed tomography (CT) and intraoperative fluoroscopy (FL). We reviewed literature to find novel techniques and approaches that help to decrease RE of patients and personnel. We performed PubMed search using keywords percutaneous nephrolithotomy, intraoperative fluoroscopy, radiation exposure, imaging, percutaneous access, ultrasound, computed tomography, endoscopy, reconstruction, innovations, and augmented reality. Forty-four relevant articles were included in this review. As much as 20% of patients with first diagnosed urolithiasis exceed background RE level almost 17-fold. For diagnosing purposes using low-dose and ultra-low-dose CT, as well as low-dose dual energy scan protocols can be efficient ways to decrease RE while maintaining decent accuracy. Patients with urinary stones can be effectively monitored with digital tomosynthesis, ultrasound alone or ultrasound combined with plain film of the abdomen. Percutaneous access (PCA) into the kidney can be performed with reduced or even no RE, using novel PCA methods. REs from conventional imaging techniques during diagnosis and treatment increase probability of non-stochastic radiation effects. Urologists should be aware of protocols that decrease RE from CT and FL in diagnosis and management of urinary stones. Consideration of recently developed imaging modalities and PCA techniques will also aid in adherence to the "as low as reasonably achievable" principle.

* Corresponding author.
E-mail address: psams13@gmail.com (P. Samson).
Peer review under responsibility of Second Military Medical University.

https://doi.org/10.1016/j.ajur.2019.03.007

1. Introduction

Urinary stone disease is a widespread and challenging issue to both patients and healthcare systems. It is responsible for a significant financial and psychological burden, with an increasing incidence of disease. The prevalence of kidney stones in the United States is 8.8%, with a higher proportion in men than in women (10.6% *vs*. 7.1%). Since 1994 we observed an increase in disease prevalence from one in 20 to one in 11 [1]. Nearly one-half of newly diagnosed patients would experience a recurrence within 5 years. These circumstances have driven the cost of treatment of urolithiasis up to 10 billion US dollars in 2012 [2].

From the early stages of endourology, radiographic imaging has been an essential part of renal stone surgery. In 1976, Fernström and Johansson [3] were the first to describe percutaneous stone extraction through a nephrostomy tract under radiological control at Karolinska Hospital in Sweden. Percutaneous nephrolithotomy (PCNL) has rapidly evolved since then and has replaced traditional open anatrophic nephrolithotomy for treatment of large kidney stones around the globe [4]. As PCNL has become a gold standard of treatment for renal stones >2 cm, radiation exposure (RE) has become increasingly prevalent for patients who form large renal stones and for urologists who operate on them.

RE during stone episodes can be quite extensive during the diagnostic, therapeutic, and follow-up periods. Average RE dose for United States citizens is 3.1 mSv per year [5]. Computed tomography (CT) use in clinical practice has increased drastically in last 3 decades. Ferrandino et al. [6] reported that as much as 20% of patients with urolithiasis during their disease course can exceed 1-year RE limit of 50 mSv established by the International Commission on Radiation Protection. Also, each CT scan gives much more ionization energy now than 30 years ago [7]. Data suggest that radiation from CT scan use in 2007 may be related to 29 000 new cancer cases just within the United States [8]. Concerns about cumulative radiation effects have obliged more centers to develop ways to decrease RE of patients and personnel.

2. RE: The stone "episode"

2.1. Reduction of RE during diagnosis

Although the non-contrast CT scan (NCCT) is the gold standard in diagnosis of nephrolithiasis, the American Urology Association (AUA) and European Association of Urology consider ultrasound as the first line diagnostic tool for vulnerable populations (*i.e*. children and pregnant women) [9]. However, initial assessment of the stones cannot rely solely on ultrasound for most patients as it tends to overestimate the size of stones, especially for small stones (by 84.6% for calculi <5 mm and 27.1% for stones 5–10 mm) [10]. Consequently, other CT-based protocols have been developed, including low-dose CT (LDCT) and ultra-low-dose CT (ULDCT). Rob et al. [11] conducted a systematic review comparing these protocols to conventional NCCT. They defined ULDCT and LDCT as <1.9 mSv and <3.5 mSv, respectively, while standard CT delivers 4.5–5.0 mSv per scan. The authors found that UDLCT and LDCT scans had comparable results to conventional NCCT scan with sensitivities of 90%–100% and specificities of 86%–100% for detecting urolithiasis across all studies. However, the alternative protocols were not as effective for calculi <3 mm in size and for patients with BMI >30 kg/m^2. Usage of tin-filters for the additional spectral shaping of the X-ray beam can further decrease RE while maintaining image quality that is comparable to standard NCCT scan [12].

Different reconstructive techniques exist that improve image resolution of CT while using lower radiation dosage. Tenant et al. [13] reported comparison of a novel modeled-based iterative reconstruction (MBIR) method compared to the more commonly used adaptive statistical iterative reconstruction (ASIR). Researchers were able to reduce radiation dose by 58% compared with the already low dose ASIR 30% reconstruction. MBIR is a complex CT algorithm that integrates several parameters that are not included in earlier algorithms to decrease computational requirement and speed up scans [14]. Through this algorithm, the image quality is improved while also reducing RE to the patient [15]. This was achieved without loss in diagnostic quality for obstructing ureteral calculi and renal calculi >3 mm.

2.2. Reduction of RE during follow-up

Digital tomosynthesis (DT) is a new technology based on conventional X-ray tomography. A computer-controlled motorized tube crane moves X-ray tube to a series of positions along a horizontal path, acquiring a projection image on a flat-panel detector at each position. The software then recreates number of coronal images at a fixed slice thickness. DT was found to be comparable imaging modality to NCCT scan for the detection of the intrarenal stones, without significant effect from stone size, BMI and adequate reproducibility among multiple readers. Also, effective dose (ED) of DT is about 0.8 mSv—only slightly higher than 0.6 mSv of conventional plain film of the abdomen (kidney, ureter, and bladder). As such, DT is an appealing imaging modality for surveillance of patients with nephrolithiasis [16].

For ureteral stones, ultrasound can be a good alternative if observation of distal ureteral stones is offered [17]. The Imaging Pilot Panel of the AUA recommends that ultrasound and KUB can be used to observe radiopaque calculi less than 10 mm in diameter with minimal to moderate hydronephrosis and no evidence of kidney damage [18]. The combination of ultrasound and KUB in this setting provides adequate sensitivity/specificity of stone detection with minimal RE and reduced cost compared to conventional NCCT.

3. RE during percutaneous surgery

3.1. Current trends in decreasing RE during percutaneous renal access

Practical methods have been developed in attempt to decrease RE during percutaneous access (PCA). Blair et al. [19] offered a reduced fluoroscopy (FL) protocol which included usage of recent images instead of initial FL, marking the field of interest, synchronization FL with end of expiration, saving the last image of the monitor, special training of FL technician, lowering the settings to "low dose", pulse FL settings, placement of the safety and guide wire using tactile cues. Mean FL time decreased from 175.6 s to 33.7 s after the implementation of the protocol ($p < 0.001$).

Hanna et al. [20] offered similar techniques to reduce RE during FL guided access. They recommended locking the C-arm so that it only moves in and out over the operative field. Second, the stone position is marked as well as the "line of attack". Third, continuous screening is avoided. And finally, protracted attempts to manipulate the guidewire into the ureter are discouraged. They were able to reduce FL time by two-thirds. This group, as well as others, found that using pulse mode rather than continuous mode FL significantly decreased total FL time [19—21].

4. Novel access techniques

4.1. Cone beam CT-guided access and control

Cone beam CT (CBCT) is a novel C-arm that capable of obtaining both FL images and CT scans intra-operatively. The next systems are available on the market for clinical use: DynaCT (Siemens Medical Solutions, Forchheim, Germany), XperCT (Philips Medical Systems, Eindhoven, the Netherlands), and Innova CT (GE Healthcare, Waukesha, Wisconsin, USA) [22]. In 2012 Roy et al. [23] reported their retrospective study of 52 patients in whom PCA was done using CBCT (UroDyna, Siemens). It worth saying that difference in residual stone detection was significantly lower only for stones that were 2 mm or smaller in comparison with CT. There was no difference in the discovery of calculi larger than 2 mm. The surgeon was able to avoid colonic injury in a patient with a retrorenal colon that was not detected by conventional CT. In another patient, the surgeon changed puncture site because of newly discovered low-lying pleura. Stone protocol CT exposed patients to an ED of 8.5 mSv. CBCT created the ED 9.9 mSv (two 8 s running periods). However, it represented 30% of the RE received during PCNL, with the 70% of the remaining dose caused by FL. Using this technology for PCA offers a unique chance to avoid rare but potentially hazardous complications [24].

4.2. Laser guided complex punctures with UroDyna CT

In patients with complex renal anatomy, cross-sectional and three dimensional (3D) imaging techniques with laser guidance may facilitate the time needed for a successful puncture and reduce the risk of intraoperative complications. Ritter et al. [25] published results of the first study (*ex-vivo*) using laser-guided PCA with UroDyna CT in 2013. In 2015, the same group published results of this technique in human subjects [26]. In this study, UroDyna CT scans were obtained preoperatively; then the C-arm was placed in Bull's eye position, and the laser crosshair indicated the place of puncture. During the procedure, the needle is held in-line with laser cross. The location of the needle can be controlled anytime using FL that shows the roadmap regardless of C-arm position. Confirmation of proper entrance into a renal calyx is drainage of urine. Investigators included 27 patients in this study. Twenty-four punctures were successful (89%). Time of image acquisition and 3D rendering was less than 2 min. Medium planning time was <5 min. Median puncture time starting with the insertion of the needle was 30 s. Median FL time during and after a puncture to check needle position was 0.7 min. Mean radiation dosages caused by FL during PCA were 0.0969 mSv and 6.11 mSv by the DynaCT scan for puncture planning.

Unfortunately, this technique carries higher RE than conventional FL. However, the radiation dose is lower than during standard CT guided kidney PCA. Thus laser-guided approach using DynaCT should be reserved for patients with complex anatomy, uncertain ultrasound findings, and unsuccessful initial FL guided puncture.

4.3. The laser direct alignment radiation reduction technique (DARRT)

Another laser guided technique for PCA was described by Khater et al. [27] in 2016. To minimize RE to the patient and surgeon, the investigators used a special laser aiming beam attachment on the regular C-arm system. The study team designed special bench-top model of the kidney for this investigation. During the puncture of the desired calyx tip and hub of the 18-gauge Chiba needle was aligned to the laser. Insertion of the needle into the desired calyx was controlled by the tactile feedback. Then surgeon rotated the C-arm 30° in the opposite direction to determine the needle depth. Effective puncture was checked up by an objective reviewer by looking through the clear undersurface of the model. The primary endpoint was FL time. Result showed that DARRT group had significantly lower FL time (7.09 s *vs*. 13.93 s, $p = 0.001$). There were three groups of the surgeon based on the level of expertise (attendings, residents and students). Students' group reported that DARRT system was easier to use 2.56 *vs*. 4.89 points ($p<0.001$).

4.4. Ultrasound-guided access

Although ultrasound technology is not new, there are only few studies that compare PCA under FL and ultrasound guidance. Interestingly, its use has not been widely adopted in the United States by urologists. Chi et al. [28] reported results of their study devoted to PCA and tract dilation under ultrasound control. FL was only used at the end of the procedure in the ultrasound group for the nephrostomy tube placement. They remarked no statistical significant differences between mean operative time. Mean FL time in ultrasound guided group was 17.7 ± 13.3 s and mean RE was 3.1±3.2 mGy, which were significantly lower than FL group measurements (FL time was 182.9±119.0 s and RE was 47.5±52.3 mGy). Basiri et al. [29] reported results of their randomized controlled trial in which they compared ultrasound and FL PCA. They estimated no statistically significant difference between ultrasound and FL groups in the following: Successful access to the collecting system and target calyx (94% and 90% in ultrasound group to both 96% in FL group), rate of intraoperative bleeding and need for embolization. The only parameters that were significantly different were duration to access (ultrasound group 11±3.5 min *vs.* 5.5±1.7 min in FL group, $p<0.0001$) and duration of RE (0.69±0.26 min in ultrasound group compared to 0.95±0.24 min in FL patient group, $p<0.0001$). Another way they suggested to decrease RE is to use the ultrasound at the end of the procedure to look for residual stones, especially non-opaque and semi-opaque ones.

4.5. Computer-assisted ultrasonic guidance

Freehand ultrasound-guided access requires a substantial amount of 2-handed coordination for proper needle targeting. To resolve this issue, Skenazy et al. [30] developed a novel computer ultrasound guidance system and reported *in-vitro* on a porcine model. The computer-assisted ultrasonic guidance system (CUGS) is attached to the ultrasound transducer. It estimates needle position and sends the signal back to the computer. The computer captures live ultrasound images and superimposes the virtual needle guide onto the monitor. Calibration time is 30 s to ensure the accuracy of the model. The needle is then advanced and observed to follow the track projected by the computer under control of the ultrasound.

Freehand, needle guided, CUGS and CUGS with support arm techniques were compared in this study. Researchers also divided subjects performing PCA based on their level of expertise (students, residents, fellows, and attendings). CUGS decreased the time of the targeting and increased precision. Usage of support arm CUGS improved visualization of the needle tip compared to CUGS alone. This technique can facilitate renal targeting by clinicians regardless of their expertise. However, inexperienced users benefited the most from the introduction of the method.

4.6. Ultrasound-guided access combined with "all-seeing needle"

Inaccurate needle placement can cause unwanted injury to the kidney or surrounding organs and is sometimes not recognized until after the operation. In 2011, Bader et al. [31] reported results of their novel combination of ultrasound and optical puncture system to allow for visually guided direct control of the needle, limiting the chances of puncture-related complications. Researchers enrolled 15 patients in the study. The system is made up of sterilizable microfiber optics of 0.9-mm and 0.6-mm diameter, with a resolution of 6000 and 10 000 pixels (PolyDiagnost, Pfaffenhofen, Germany). The needle contains a Y-stylet which has an outlet for an irrigation system. An optical fiber is attached via a zoom ocular and light adapter to the standard camera system and xenon light source. Access is performed under ultrasound control with a 3.5 MHz probe. The surgeon uses the posterior axillary line as an entrance point and entered the pelvicaliceal system at lower posterior calyx. As soon as the calyx is identified, the optical needle is advanced through the subcutaneous tissue, muscle layer, and surrounding fatty tissue into the collecting system under direct visualization. After successful placement of the needle into the system, it is confirmed endoscopically, and placement of the wire is monitored using FL.

All 15 patients had successful PCA—11 patients required only one puncture while four patients needed additional attempts due to suboptimal placement of the needle. Mean operative time was 101.4 min. No significant complications were noted. Four patients had residual stones with three requiring subsequent ureterorenoscopy. Although this technique has not been directly compared to conventional techniques, it has the advantage of confirming proper placement of the needle before dilation, theoretically improving the safety of PCA.

4.7. Intraoperative ultrasound augmentation with preoperative magnetic resonance imaging (MRI) for PCA

Similar to the MRI-ultrasound fusion technique for prostate biopsy, a technique was developed by Li et al. [32] that augments intraoperative ultrasound with preoperative MRI during PCA to enhance navigation and avoid damage to surrounding structures without any ionizing radiation. In this technique, preoperative precession (True Fast Image with Steady-state Precession) magnetic resonance sequence (Siemens MAGNETOM Trio trim machine) is used to acquire volume data. The MR volume data are then transferred to the augmented-ultrasound based guidance system and the anatomy of the kidney undergoes 3D reconstruction. The surgeon performs preoperative ultrasound scanning (Mindray DC-7 machine with 3.5 MHz abdominal probe) of the kidney after positioning of the patients on maximal exhalation in orthogonal position. Both transducer and puncture needle have optically tracked markers. After MRI augmentation of ultrasound completed, the two trajectories show the puncture pathway each contained entrance site on the skin target. Then puncture with the plastic needle is done with a guide attached to the probe and by following the path. After each puncture, MRI is performed to ensure success of the attempt. The authors evaluated the proposed image guidance framework in two stages: First, evaluation of the registration performance regarding accuracy, precision, and processing time measured on human data (four volunteers); second, four urologists evaluated puncture accuracy and perceptual quality on kidney phantoms.

The mean registration accuracy regarding the root means square target registration error was 3.53 mm. The root means square target distance from the registered feature points to their average was 0.81 mm. The mean operating time of the registration was 6 min and 4 s.

The technique not only eliminates radiation hazard, but also uses complex anatomical reconstruction to optimize 3D visualization of the kidney to relegate the disadvantages of pure ultrasound-guided access. The cost of MRI may, however, not be worth RE reduction in the current era.

4.8. Ultrasound-guided puncture under electromagnetic (EMT) augmentation

SonixGPS is another novel real-time ultrasound navigation system designed to improve accuracy of PCA without any

RE. This method showed decreased time of puncture and increased accuracy in a pig model [33]. The first human studies showed that PCNL done with SonixGPS was safe and highly efficacious [34]. Recently Li et al. [35] performed another retrospective study to compare outcomes of conventional PCNL with SonixGPS PCNL. Conventional ultrasound guidance PCNL was done using Siemens US machine (Siemens, Germany). Real-time ultrasound guiding PCNL was performed using a SonixGPS navigation system (Ultrasonic Medial Corporation, Canada), which consisted of an EMT transmitter, the SonixGPS ultrasound probe, and an 8 cm 18 gauge SonixGPS proprietary needle. The transducer is positioned close to operation area for tracking and positioning of the needle. For in-plane procedures, the surgeon will see orientation bars, on the lower right side of the monitor. This helps guide needle and hand position. For out-of-plane puncture, X or circle marks on the monitor directs the surgeon.

In the study by Li et al. [35], 37 patients in each group were matched with respect to age, BMI, and stone size. There was a greater number of patients in the SonixGPS group without dilation in the target calyx (17 *vs.* 7, $p<0.024$). The statistical analysis revealed no difference for operating time, duration of the hospital stay or stone clearance rate. The SonixGPS group had lower rate of hemoglobin decrease, lower number of attempts and shorter time of puncture attempt compared to conventional ultrasound guidance group.

In 2016, Chau et al. [36] reported results of their study of 18 patients where they used a similar ultrasound machine with the built-in navigation system under magnetic field (My Lab Twice by Esaote, Milano, Italy). It shares the same core principle components as SonixGPS except it is performed free hand without the use of a needle-guide attached to the transducer. This allows for greater degree of freedom in choosing the angle of entry. In the study, no radiation was utilized during the puncture step while mean FL time was 74.6 s throughout the entire procedure. Of the 18 patients, 15 of them had successful punctures on the first attempt while the other three on the second.

4.9. Direct endoscopic visualization combined with conventional FL control

Morbid obesity, non-hydronephrotic kidneys, and calyces filled with stones can make PCA a challenging task. Khan et al. [37] described the use of uteroscopic guided percutaneous kidney access to circumvent these challenges. A fiberoptic ureterorenoscope is navigated into desired calyx through a ureteral access sheath. The ureteroscope is used as a target for the needle puncture under FL. It could also be used for laser lithotripsy of stone that is obstructing access to the desired calyx. Another application of the endoscope was relocation of safety wire from the renal pelvis down the ureter for more secure wire placement. Ureterorenoscope also provided direct visualization of the needle tip within the calyx after the puncture, balloon dilation and sheath placement, improving the safety of PCA. Combined antegrade and retrograde access to the pelvis allowed access to more areas of pelvicalyceal system. Investigators successfully applied this technique in 12 patients. Eleven of 12 had PCNL. Usually, only single attempt was done to achieve successful PCA. There were no bleeding complications in the 10 patients. Seven patients were considered completely stone-free. This approach has been successful in all patients, regardless of body habitus, stone burden, or renal ectopy.

4.10. Direct endoscopic visualization combined with ultrasound-guided access

The ureteroscopy-guided percutaneous renal access technique is used to obtain precise access into complex collecting systems, however it still required the use of FL. Following the trend to decrease RE of the patient, Alsyouf et al. [38] published the study that compares traditional PCNL under FL guidance with PCNL where access was done with the combined ultrasound and endoscopic control. In this retrospective study, 40 patients were included, with 20 in each cohort. While patients were in prone split leg position, the surgeon performs flexible ureterorenoscopy without FL and identifies the ideal calyx for puncture. The ultrasound probe (GE LOGIQe with a 4c probe, GE Healthcare) is then used to visualize the tip of the ureteroscope in the calyx of choice. A Chiba needle (Cook Medical, Bloomington, IN, USA) is used for PCA under endoscopic control. A 0.018-inch Mandril wire from Aprima™ access set is placed through the needle, basketed endoscopically, and pulled into the proximal ureter. Balloon dilation and sheath placement is done under direct ureteroscopic visualization. The ureteroscope can be left at the ureteropelvic junction to prevent migration of the stone fragments into the ureter. At the end of the procedure flexible renoscopy is done in the retrograde fashion with the flexible ureteroscope. After a nephrostomy or stent is positioned for post-procedural drainage, one shot FL is done to confirm correct placement. Considerable reductions in mean FL access time and mean total FL time were achieved in comparison to the conventional approach (3.5 s *vs.* 915.5 s and 8.8 s *vs.* 1028.7 s, respectively). Mean operative time was 232 min, estimated blood loss was 111 mL, the stone-free rate was 65%, and the complication rate was 25%, which were not significantly different from the standard fluoroscopic approach.

4.11. Ureteroscopy assisted PCNL with EMT guidance

In 2017 Lima et al. [39] published results of their prospective proof-of-concept phase 1 trial that involved using EMT navigation system combined with direct endoscopic visualization in performing PCA. The authors enrolled 10 patients who each underwent preoperative CT scan with 3D reconstruction. They used the commercially available Aurora EMT system (Northern Digital, Waterloo, Canada), two sensor interface units, system control center, one Chiba needle and one ureteral catheter with the Aurora EMT sensor during the procedure. Researchers placed the EMT sensor in the calyx of the interest using a digital flexible ureteroscope. The ultrasound scan was used to confirm that there were no structures on the way of the anticipated puncture. A Chiba needle with the EMT sensor is then used to perform puncture using EMT navigation displayed on the separate monitor. Proper needle entry into the calyx confirmed endoscopically as described previously [37,38]. The stylet with the sensor is then removed and guide-wire is inserted. Balloon dilation and sheath placement are done under endoscopic control.

There were no complications in the study. This technique has significant advances like constant monitoring in 3D mode, possibility to make slight changes of needle trajectory, and shorter time of the procedure (median time to successful puncture was 20 s). Most importantly, the authors were able to perform percutaneous renal access without RE entirely. Table 1 outlines the advantages and disadvantages of each of the percutaneous access techniques described above.

5. Novel non-invasive technology

For patients who wish to avoid procedures requiring anesthesia, ultrasonic propulsion of kidney stones may be a promising technology. In 2016, Harper et al. [40] reported the first human clinical trial of ultrasound propulsion of

Table 1 Comparative results of different access techniques.

Access technique	Mean RE/FL time during PCA	Pros	Cons
Cone beam CT-guided access and control	9.9 mSv/—	Helps to perform puncture in patients with abnormal anatomy. Low-risk of complications	Carries higher RE and requires more time for PCA
Laser guided complex punctures with UroDyna CT	0.0969 mSv/—	Good for patients with complex anatomy, uncertain ultrasound findings, unsuccessful FL guided punctures	Immediate pre-procedural CT (6.11 mSv) is required, which increases RE and time of procedure
The laser direct alignment radiation reduction technique	—/7.09 s	Decreases mean access FL time. Easier technique for non-experienced surgeons	Requires special equipment
Ultrasound-guided access	—/17.7 s	Helps to decrease RE during PCA, while providing high success rate of PCA	PCA time was significantly longer in ultrasound guided group
Computer-assisted ultrasonic guidance	RE was eliminated	Facilitates renal targeting regardless level of surgeon's expertise and helps to eliminate RE	Requires special equipment
Ultrasound-guided access combined with "all-seeing needle"	RE was eliminated	Eliminates RE and simultaneously allows confirmation of proper placement of the needle by direct visualization of the pelvis and calyces	Requires special equipment
Intraoperative ultrasound augmentation with preoperative MRI for PCA	RE was eliminated	Eliminates RE during the procedure, and also gives complex 3D reconstruction. Very useful in cases where X-ray exposure contraindicated, and complex visualization is required	Pre-surgical MRI with marking is required
Ultrasound-guided puncture under EMT augmentation	RE was eliminated	Improves tracking of the needle (shorter time of puncture, lower number of attempts) and eliminates RE during PCA	Requires special equipment
Direct endoscopic visualization combined with conventional FL control	RE can be potentially decreased due to better visualization	Can be used in patients with anticipated difficulties during PCA (obesity, significant stone burden, non-dilated pelvicalyceal system, nephroptosis). Does not require special equipment	FL is still main visualization approach. Requires assistant who can control ureteroscope
Direct endoscopic visualization combined with ultrasound-guided access	—/3.5 s	Helps to significantly decrease FL time. Does not require special equipment. Helps to confirm correct PCA by direct visualization	Requires assistant who can control ureteroscope
Ureteroscopy assisted PCNL with electromagnetic guidance	RE was eliminated	Potentially eliminates the need for RE. Helps to confirm correct PCA by direct visualization. Provides constant 3D monitoring through the procedure	Requires special equipment

—, this number was not indicated or provided in the paper that was referenced; 3D, three dimensional; CT, computed tomography; EMT, electromagnetic; FL, fluoroscopy; MRI, magnetic resonance image; PCA, percutaneous access; PCNL, percutaneous nephrolithotomy; RE, radiation exposure.

kidney stones in 15 patients with stones of varying sizes and location. The investigational device was a diagnostic ultrasound platform with the capability of producing focused ultrasonic pulses of higher amplitude and longer duration than conventional ultrasound. The authors created a custom "Push sequence", which is optimized with a standard diagnostic probe (HDI C5-2 curvilinear array, Philips Ultrasound, Andover, MA, USA). The "Push sequence" is generated between two B-mode imaging frames and creates a real-time moving image of the stone in motion. The operator activates the "Push" by simply touching the stone on touchscreen displaying the ultrasound image. The stones were able to be repositioned in a more favorable location in 14 of the 15 patients.

Several other advantages of this novel technology were noted by the authors. Ultrasound propulsion can facilitate stone passage in some patients. Intrarenal fragments could be propelled into the proximal ureter while they are still small enough to pass, rather than waiting for them to grow to a size that requires surgical management. Moreover, the procedure can be performed successfully without any sedation. Lastly, clusters of small stones were able to be distinguished from a large stone using the "Push sequence". Utilizing this technology can potentially avoid RE from repeat cross-sectional imaging or endourologic procedures requiring FL.

6. Conclusion

RE of patients with urolithiasis carries the risk of radiation-induced cancers. High volume stone surgeons are also at risk of harmful radiation effects in the course of treating patients, and should practice with care for the as low as reasonably achievable principle. Many methods to reduce diagnostic and therapeutic exposures have been explored, and the most successful ones will be those which are low-cost, effective in reducing RE, maintain optimal treatment success rates, and are easy to incorporate into clinical practice. Systematic reduction of RE will yield tangible health benefits to both the urologists and the patients.

Urologist must familiarize themselves with emerging technologies which allow us to provide better care for stone patients and ourselves. Training in these techniques for new urologists and stone specialists will be critical to incorporate a greater awareness of RE and the means to reduce it in the future.

Author contribution

Study concept and design: Patrick Samson, Arthur Smith.
Data acquisition: Bohdan Baralo.
Data analysis: Bohdan Baralo.
Drafting of manuscript: Bohdan Baralo.
Critical revision of the manuscript: Patrick Samson, David Hoenig.
Reviewing article: Arthur Smith.
Manuscript enhancement: Arthur Smith.

Conflicts of interest

The authors declare no conflict of interest.

References

[1] Scales Jr CD, Smith AC, Hanley JM, Saigal CS. Prevalence of kidney stones in the United States. Eur Urol 2012;62:160—5.
[2] Litwin MS, Saigal CS. Urologic Diseases in America. US Department of Health and Human Services, Public Health Service, National Institutes of Health, National Institute of Diabetes and Digestive and Kidney Diseases. Washington, DC: US Government Printing Office; 2012. p. 314—46.
[3] Fernström I, Johansson B. Percutaneous pyelolithotomy. A new extraction technique. Scand J Urol Nephrol 1976;10:257—9.
[4] Ghani KR, Andonian S, Bultitude M, Desai M, Giusti G, Okhunov Z, et al. Percutaneous nephrolithotomy: update, trends, and future directions. Eur Urol 2016;70:382—96.
[5] National Council on Radiation Protection and Measurements. Ionizing radiation exposure of the population of the United States. 2015, May 29 [Press release], https://ncrponline.org/publications/reports/ncrp-report-160.
[6] Ferrandino MN, Bagrodia A, Pierre SA, Scales Jr CD, Rampersaud E, Pearle MS, et al. Radiation exposure in the acute and short-term management of urolithiasis at 2 academic centers. J Urol 2009;181:668—72.
[7] Neisius A, Wang AJ, Wang C, Nguyen G, Tsivian M, Kuntz NJ, et al. Radiation exposure in urology: a genitourinary catalogue for diagnostic imaging. J Urol 2013;190:2117—23.
[8] Berrington de González A, Mahesh M, Kim KP, Bhargavan M, Lewis R, Mettler F, et al. Projected cancer risks from computed tomographic scans performed in the United States in 2007. Arch Intern Med 2009;169:2071—7.
[9] Tzou DT, Usawachintachit M, Taguchi K, Chi T. Ultrasound use in urinary stones: adapting old technology for a modern-day disease. J Endourol 2017;31(S1):S89—94.
[10] Sternberg KM, Eisner B, Larson T, Hernandez N, Han J, Pais VM. Ultrasonography significantly overestimates stone size when compared to low-dose, noncontrast computed tomography. Urology 2016;95:67—71.
[11] Rob S, Bryant T, Wilson I, Somani BK. Ultra-low-dose, low-dose, and standard-dose CT of the kidney, ureters, and bladder: is there a difference? Results from a systematic review of the literature. Clin Radiol 2017;72:11—5.
[12] Dewes P, Frellesen C, Scholtz JE, Fischer S, Vogl TJ, Bauer RW, et al. Low-dose abdominal computed tomography for detection of urinary stone disease—impact of additional spectral shaping of the X-ray beam on image quality and dose parameters. Eur J Radiol 2016;85:1058—62.
[13] Tenant S, Pang CL, Dissanayake P, Vardhababhuti V, Stuckey C, Gutteridge C, et al. Intra-patient comparison of reduced-dose model-based iterative reconstruction with standard-dose adaptive statistical iterative reconstruction in the CT diagnosis and follow-up of urolithiasis. Eur Radiol 2017;27:4163—72.
[14] Liu L. Model-based iterative reconstruction: a promising algorithm for today's computed tomography imaging. J Med Imaging Radiat Sci 2014;45:131—6.
[15] Wilhelm K, Schoenthaler M, Hein S, Adams F, Schlager D, Kuehhas FE, et al. Focused dual-energy CT maintains diagnostic and compositional accuracy for urolithiasis using ultralow-dose noncontrast CT. Urology 2015;86:1097—102.
[16] Cabrera FJ, Kaplan AG, Youssef RF, Tsivian M, Shin RH, Scales CD, et al. Digital tomosynthesis: a viable alternative to noncontrast computed tomography for the follow-up of nephrolithiasis? J Endourol 2016;30:366—70.
[17] Moesbergen TC, de Ryke RJ, Dunbar S, Wells JE, Anderson NG. Distal ureteral calculi: US follow-up. Radiology 2011;260:575—80.
[18] Fulgham PF, Assimos DG, Pearle MS, Preminger GM. Clinical effectiveness protocols for imaging in the management of

ureteral calculous disease: AUA technology assessment. J Urol 2013;189:1203—13.
[19] Blair B, Huang G, Arnold D, Li R, Schlaifer A, Anderson K, et al. Reduced fluoroscopy protocol for percutaneous nephrostolithotomy: feasibility, outcomes and effects on fluoroscopy time. J Urol 2013;190:2112—6.
[20] Hanna L, Walmsley BH, Devenish S, Rogers A, Keoghane SR. Limiting radiation exposure during percutaneous nephrolithotomy. J Endourol 2015;29:526—30.
[21] Durutovic O, Dzamic Z, Milojevic B, Nikic P, Mimic A, Bumbasirevic U, et al. Pulsed versus continuous mode fluoroscopy during PCNL: safety and effectiveness comparison in a case series study. Urolithiasis 2016;44:565—70.
[22] Wallace MJ, Kuo MD, Glaiberman C, Binkert CA, Orth RC, Soulez G, et al. Three-dimensional C-arm cone-beam CT: applications in the intervention al suite. J Vasc Interv Radiol 2008;19:799—813.
[23] Roy OP, Angle JF, Jenkins AD, Schenkman NS. Cone beam computed tomography for percutaneous nephrolithotomy: initial evaluation of a new technology. J Endourol 2012;26:814—8.
[24] Vicentini FC, Botelho LAA, Braz JLM, Almeida ES, Hissano M. Use of the Uro Dyna-CT in endourology—the new frontier. Int Braz J Urol 2017;43:762—5.
[25] Ritter M, Rassweiler MC, Häcker A, Michel MS. Laser-guided percutaneous kidney access with the Uro Dyna-CT: first experience of three-dimensional puncture planning with an ex vivo model. World J Urol 2013;31:1147—51.
[26] Ritter M, Rassweiler MC, Michel MS. The Uro Dyna-CT enables three-dimensional planned laser-guided complex punctures. Eur Urol 2015;68:880—4.
[27] Khater N, Shen J, Arenas J, Keheila M, Alsyouf M, Martin JA, et al. Bench-top feasibility testing of a novel percutaneous renal access technique: the laser direct alignment radiation reduction technique (DARRT). J Endourol 2016;30:1155—60.
[28] Chi T, Masic S, Li J, Usawaschintachit M. Ultrasound guidance for renal tract access and dilation reduces radiation exposure during percutaneous nephrolithotomy. Adv Urol 2016;2016:3840697.
[29] Basiri A, Ziaee AM, Kianian HR, MehrabiS, Karami H, Moghaddam SM. Ultrasonographic versus fluoroscopic access for percutaneous nephrolithotomy: a randomized clinical trial. J Endourol 2008;22:281—4.
[30] Skenazy JF, Mirabile G, Hruby GW, Lauer-Amold I, Gupta M, Landman J. Comparison of manual and computer assisted ultrasonic guidance for transparenchymal percutaneous renal needle placement. J Urol 2009;181:867—71.
[31] Bader MJ, Gratzke C, Seitz M, Sharma R, Stief CG, DesaiM. The "All-seeing needle'': initial results of an optical puncture system confirming access in percutaneous nephrolithotomy. Eur Urol 2011;59:1054—9.
[32] Li ZC, Li K, Zhan HL, Chen K, Gu J, Wang L. Augmenting intraoperative ultrasound with preoperative magnetic resonance planning models for percutaneous renal access. Biomed Eng Online 2012;11:60.
[33] Rodrigues PL, Vilaça JL, Oliveira C, Cicione A, Rassweiler J, Fonseca J, et al. Collecting system percutaneous access using real-time tracking sensors: first pig model in vivo experience. J Urol 2013;190:1932—7.
[34] Li R, Li T, Qian X, QI J, WU D, LIU J. Real-time ultrasonography-guided percutaneous nephrolithotomy using SonixGPS navigation: clinical experience and practice in a single center in China. J Endourol 2015;29:158—61.
[35] Li X, Long Q, Chen X, He D, He H. Assessment of the SonixGPS system for its application in real-time ultrasonography navigation-guided percutaneous nephrolithotomy for the treatment of complex kidney stones. Urolithiasis 2017;45:221—7.
[36] Chau HL, Chan HC, Li TB, Cheung MH, Lam KM, So HS. An innovative free-hand puncture technique to reduce radiation in percutaneous nephrolithotomy using ultrasound with navigation system under magnetic field: a single-center experience in Hong Kong. J Endourol 2016;30:160—4.
[37] Khan F, Borin JF, Pearle MS, McDougall ME, Clayman RV. Endoscopically guided percutaneous renal access: "Seeing is believing". J Endourol 2006;20:451—5.
[38] Alsyouf M, Arenas JL, Smith JC, Myklak K, Faaborg D, Jang M, et al. Direct endoscopic visualization combined with ultrasound guided access during percutaneous nephrolithotomy: a feasibility study and comparison to a conventional cohort. J Urol 2016;196:227—33.
[39] Lima E, Rodrigues PL, Mota P, Carvalho N, Dias E, Correla-Pinto J, et al. Ureteroscopy-assisted percutaneous kidney access made easy: first clinical experience with a novel navigation system using electromagnetic guidance (IDEAL Stage 1). Eur Urol 2017;72:610—6.
[40] Harper JD, Cunitz BW, Dunmire B, Paun M, Lee F, Ross S, et al. First in human clinical trial of ultrasonic propulsion of kidney stones. J Urol 2016;195:956—64.