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Fluoroless Endourological Surgery for Stone Disease: a Review of the Literature—Tips and Tricks

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Abstract

Purpose of Review Urologists are at significant risk due to radiation exposure (RE) from endourological procedures for stone disease. Many techniques described have shown a reduction of RE. The purpose of this article is to review available protocols to decrease RE during such procedures and provide tips and tricks for their implementation.

Recent Findings Several low-radiation and radiation-free protocols for percutaneous nephrolithotomy and flexible ureteroscopy have been described as an attempt to reduce RE during surgery. Beginning with specific checklists to ensure adequate C-arm usage, fluoroless procedures are based on endoscopic assessment, tactile guidance, and use of ultrasound to avoid fluoroscopy.

Summary A specific preoperative checklist and low radiation or complete fluoroless radiation endourological procedures have shown to be effective, feasible, and safe. It is recommended for urologists to be aware of the risks of RE and apply the "ALARA" (As Low As Reasonably Achievable) protocols.

Keywords Endourology · Radiation · Fluoroless · PCNL · Flexible ureteroscopy · Urolithiasis

Introduction

Many techniques have been described to result in a reduction in radiation exposure (RE) during endourological procedures following "ALARA" (As Low As Reasonably Achievable) [1] protocols, in which the main components are education and raising awareness of the risks of radiation (to both the patient and healthcare personnel). When reducing or avoiding radiation during procedures, it needs to be ensured that optimal surgical results are obtained without an increase in complications. In accordance with this goal, Ngo and colleagues achieved a reduction in the use of fluoroscopy by 24% simply by recording their intraoperative fluoroscopy screening time (FST), without changes in operative times [2].

Urologists are at significant risk due to RE when performing percutaneous nephrolithotomy (PCNL), retrograde intrarenal surgery (RIRS), and ureteroscopy (URS), all of which are commonly used in clinical practice. It is of paramount importance to be aware of these risks and of the methods, protocols, and techniques designed to avoid them, as described below. The purpose of this article is to review available protocols to decrease RE during endourological procedures.

Checklists to Reduce Radiation Exposure

Checklists to reduce RE have been described with the aim of ensuring that the operating room is preset in an appropriate way for this purpose. Such checklists start with an exhaustive evaluation of radiological imaging [13•]. All fluoroless protocols begin by placing the C-arm so that it is ready for use if necessary as patient safety is the priority [15••, 29]. With regard to operating room setup, the checklists include adequate patient positioning on the surgical table to avoid

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interfering artifacts in the X-ray field. Adequate C-arm positioning must be ensured to center the image and to lower the X-ray tube as much as possible. Also, the C-arm should be preset to have the correct disposition of images and dosage according to the patient's weight as well as the pulse and collimation [3, 4, 5, 6, 7, 8, 9, 13•]. Finally, all personnel in the operating room should adopt radiation protection measures such as lead glasses, body and neck aprons, and gloves [10, 13•], as well as the use of dosimeters to ensure continuous evaluation of RE. A pre-fluoroscopy quality checklist proposed by Kokorowski et al. resulted in a 67% (0.88 min) reduction in FST [11]. Checklist measures are summarized in Table 1.

Low-Radiation Ureteroscopy

Several low-radiation RIRS protocols have been described in an attempt to reduce RE during the procedure. The primary factor that must be taken into consideration in such protocols is reduction in the FST. Hernanz-Schulman [12] et al. described ten steps to reduce radiation doses during pediatric ureteroscopy. Meticulous preoperative procedure planning, pulsed fluoroscopy (instead of continuous fluoroscopy), and sensitive and tactile guidance were identified as critical in decreasing FST [13, 14]. By implementing these recommendations, a reduction of FST by more than 70 s has been described [13•], while a reduction by 65 s was described using only pulsed fluoroscopy [14].

Hsi et al. [15••] described an almost complete fluoroless protocol during surgery that required the use of fluoroscopy in only 25% of patients because of surgical difficulties (insertion of the ureteral access sheath (UAS) and impossibility of finding the stone). The protocol considered the preoperative assessment of the patient's anatomy and stone morphology, the equipment (C-arm, pedal) setup and positioning, and ureteral access under visual and tactile guidance, with performance of pyelography or use of fluoroscopy only if the access was difficult. The authors used two taps of fluoroscopy at the end of the procedure to place the stent.

The success and overall complication rates in all the low-radiation RIRS protocols mentioned above were similar to those seen when using the standard RIRS protocols with radiation. In their study, Greene et al. found that compared with a standard RIRS, a reduced radiation protocol showed similar operative times, results, and complication rates while reducing the radiation time by 82% [13].

Radiation-Free Ureteroscopy

Complete radiation-free RIRS surgical protocols represent an evolution from low-radiation RIRS protocols. Regarding fluoroless ureteroscopy for distal ureteral stones, Mohey

Table 1 Checklist of preoperative measures to reduce radiation exposure.

Prior to surgery	Radiation protection measures	C-arm positioning	C-arm characteristics	C-arm use
Exhaustive evaluation of radiological images	Protection glasses	Center the image (Laser guided positioning pointer)	Continuous use of fluoroscopy alarms (30 s)	Use simple pulse instead of continuous shooting
Patient positioning (to avoid interfering artifacts in the x-ray field)	Leaded trunk and neck aprons	Lowering the X-ray tube as low as possible	Total fluoroscopy timer	Make radiological captures at the end of the patient's expiration (more durable and less distorted phase)
	Leaded gloves	Setting the correct disposition of images	Built-in memory of previous images (in order to avoid continuous fluoroscopy)	Use of the pedal by the surgeon (nontechnicians or assistants)
		Dose according to the patient weight as well as the pulse		Increase the distance between the radiation source the operating room staff and the patient
				Do not use the C-arm without the spacer
				Use collimation (restriction of the irradiated area)
				According to the procedure regulate the irradiation parameters (decrease the peak of kilovoltages and milliamps—in seconds manoeuvres that do not require high resolution images)
				Reduce frames per second
				Have a fluoroscopy technician

et al. [16] showed similar operative times, stone-free rates, and complication rates compared with the standard procedure. Olgin et al. [17••] were the first to compare a completely fluoroless RIRS with a control (fluoroscopy) group; in their protocol, introduction of the guidewire and UAS was achieved by tactile feedback and gentle maneuvers, and the authors reported the same success and complication rates between the fluoroscopy and radiation-free groups. Çimen et al. [18] reported that it is possible to control introduction of the UAS by direct endoscopic visualization with a semi-rigid ureteroscope along the UAS, although they warned that direct endoscopic visualization of UAS placement could be especially complicated in men at risk of urethral injury.

Concerning the safety of fluoroless UAS placement, when the surgeon feels resistance, the recommendation is not to insert the UAS even with fluoroscopy guidance [19••]. Manzo et al. [19••] reported that a critical factor in avoiding radiation during RIRS is performance of initial access to the ureter with a hydrophilic and soft tip wire that will, most likely, avoid the risk of ureteral damage. Minimal ureteral manipulation with reduced radiation is an additional advantage of a hybrid guidewire because it functions as both an access and a working wire.

Fluoroless RIRS has also been extended to the pediatric population. Kirac et al. were able to perform radiation-free RIRS in 95% of their pediatric patients, with a success rate of 89.2% and an excellent safety profile [20]. In pediatric cases (as well as in adults), use of ultrasound as an alternative to fluoroscopy has been recommended [21••].

In all of the aforementioned studies, experienced surgeons evaluate radiation-free protocols using a retrospective study design. It will be necessary to conduct a multicenter prospective randomized controlled study to evaluate these protocols further. Additionally, it has been shown that when surgical treatment is standardized at the beginning of the learning curve and adequate training is given, inexperienced surgeons or residents achieve similar reductions in RE to experienced surgeons [22].

Tips and Tricks to Reduce Radiation During Ureteroscopy

Reduction of RE during ureteroscopy is achieved by performing the procedure based on an endoscopic assessment and tactile sensations while omitting the use of the C-arm [3, 14]. Some tips and tricks have been described for the key steps in a fluoroless procedure.

Guidewire Placement

Some authors have suggested that safe fluoroless ureteroscopy for lower ureteral stones (below the sacroiliac joint) can be performed without use of a guidewire [23]. Even so, most authors use a hydrophilic safety guidewire or hybrid wire (hydrophilic tip and PTFE shaft) to ensure a better passage to the collecting system. The guidewire is usually passed through the ureteral orifice to the renal cavities under tactile feedback. The wire is passed until there is no progression or until the ureteral orifice kinks or moves away from its position. Slight resistance can be felt when passing a ureteral stone or when the wire hits the upper pole [18, 19••, 21••, 24, 25, 26, 27, 28, 29, 30, 31].

Additionally, some authors suggest use of the length of the wire as a guide: Usually the wire will be in the collecting system if the tip of the wire is at the end of an auxiliary table or approximates the feet of a patient in the lithotomy position [15••, 17••, 21••]. If any resistance is felt or in cases of doubt, endoscopic evaluation or fluoroscopy is recommended.

Endoscopic Ureteral Assessment

Once the guidewire is in place, endoscopic ureteral assessment is recommended; most authors use a semi-rigid ureteroscope for this purpose. This will confirm correct passage of the wire into the collecting system, allow assessment of the presence of stones in the ureter, and enable passive dilation, giving the surgeon an idea of the ureteral diameter as an aid to deciding on the circumference of the UAS if necessary [21••, 23, 24, 25, 26, 27, 28, 32]. Other authors directly insert the flexible ureteroscope along (or over) the guidewire to the renal cavities [15••, 19••].

Ureteral Access Sheath

Fluoroless insertion of a UAS is a critical step as this may be the cause of ureteral damage. Some authors only recommend the performance of fluoroless sheathless procedures, while others recommend that a UAS can be used if the patient is pre-stented [17••, 21••, 25, 29]. Most authors who use a UAS place it through a working guidewire under tactile sensation, stopping if they meet resistance [19••, 21••, 26, 32]. As regards the length of insertion, in order to ensure that the UAS is kept below the ureteropelvic junction (UPJ), a mark can be made in the semi-rigid scope at the external urethral meatus, while the tip of the scope is at the UPJ. Other authors have inserted the UAS over a semi-rigid or flexible ureteroscope as an outer sheath of the scope [24, 31, 33•], inserted the UAS under vision at the level of the ureteral meatus [18], or used one tap of fluoroscopy [15••, 34].

Double J Stent Placement

Different techniques have been described for fluoroless stent placement. A thin 4.8 Fr double J stent may be placed under vision through the working channel of a semi-rigid ureteroscope [18, 20, 21••, 27, 28, 32]. After removing the scope and assuring that the wire is in the kidney, under endoscopic vision, the stent may be inserted until the mark at the distal coil is seen at the ureteral orifice [17••]; with this maneuver, the proximal coil may be controlled under ultrasound [17••, 21••, 24, 26]. Finally, the stent may be placed with a single fluoroscopy tap to control the curl of the proximal coil [15••].

Low-Radiation PCNL

Many attempts have been made over recent years to simplify, standardize, and increase the safety of kidney access for PCNL. Besides fluoroscopy and ultrasound, there are some situations in which adjunctive laparoscopy, endoscopy, or other new technologies can provide better and safer control of calyceal puncture and tract creation.

For PCNL, the supine position allows a reduction in RE since the prone PCNL can result in a 1.5- and 1.3-fold higher effective radiation doses for the lens and extremities, respectively [35]. Another trick to avoid excessive fluoroscopy is to use 50% diluted contrast with saline, as decreasing the radiopacity will reduce the X-ray intensity. Similarly, it is recommended that all radiopaque objects are removed from the surgical field (heart electrodes or any metallic objects, including parts of the surgical table).

Finally, another important step to avoid RE is to gain experience as a surgeon; as with RIRS, standardization and adequate teaching of techniques from the beginning of the learning curve are of assistance.

Endoscopic Controlled Puncture

In some situations, tract creation can be controlled under endoscopic vision with a flexible ureteroscope previously inserted in the collecting system [36]. The needle advancement also needs to be controlled by ultrasound or fluoroscopy after contrast injection through the flexible ureteroscope. With this method, it can be ensured that the needle goes precisely through the tip of the papilla, and corrections can be made if necessary. The guidewire can also be steered into the ureter using a nitinol basket through the flexible ureteroscope, establishing a through-and-through safety wire. Moreover, unless bleeding from the puncture site impairs the vision, the dilation maneuvers and the Amplatz sheath placement can also be checked endoscopically, avoiding radiation. This option is very useful for complex accesses and for anatomic abnormalities to plan the surgical strategy intraoperatively. From a technical standpoint, since there is no need to systematically use a UAS for this approach, the damage to the ureter is minimal, being similar to that caused by the open-end ureteral catheter commonly used for pyelography. The main limitation of endovision control puncture concerns those calyces occupied with stones, in which it is not possible to track either needle entrance or dilation. The kidney displacement with the needle can also hamper the endoscopic control to some extent. Special caution has to be taken in patients with infective stones, trying to minimize the intrarenal pressure during these maneuvers in order to prevent bacteremia and sepsis [37, 38].

Likewise, some authors have described the use of a flexible ureteroscope to make a precise puncture from the inside out using a Lawson puncture wire. In this approach, there is also a need for fluoroscopy and/or ultrasound to track the needle path between the renal papilla and the skin [39, 40]. Uribe and colleagues have also described the creation of a subcostal nephrostomy tract for PCNL by retrogradely firing the laser fiber through the desired calyx in a controlled perforation [41].

Finally, the possibility of controlling the needle advancement toward the calyx has been described by Bader et al. [42] using Microperc® (PolyDiagnost, Pfaffenhofen, Germany). This “all-seeing needle” consists of a 4.85 F needle through which a 0.9 mm fiber optic with 10,000 pixels can be inserted. Although the concept is very exciting, in daily practice, it is very difficult to have a clear view of the path when using this system, and fluoroscopy or ultrasound control is required to achieve a precise puncture. However, the optical puncture needle is an excellent tool to confirm optimal access to the collecting system before dilation. This system also has the option to dilate up to 8 Ch. Through this larger sheath, a guidewire can be passed under endoscopic control through the infundibulum and steered down into the ureter, making access creation easier and safer in complex situations [43].

Ultrasound-Guided Puncture

Ultrasound guidance during PCNL is an approach that has many advantages compared with fluoroscopy guidance. It can be used for renal access by practitioners of any level, and for the advanced user, it can render the procedure entirely X-ray free. Among urologists, the traditional approach for obtaining renal access has relied on fluoroscopy [44••]. When considered in the context of all renal access procedures performed globally, however, fluoroscopy guidance is used in the minority of cases. Worldwide, the vast majority of percutaneous renal entry procedures are performed by interventional radiologists, and the most common imaging technique used is ultrasound guidance [45••], whether for renal access for PCNL or for nephrostomy tube placement. From this perspective, adoption of ultrasound guidance by urologists for PCNL is achievable and could assist more urologists in obtaining their own renal access for PCNL.

To utilize ultrasound successfully for renal access, two skills are critical [46]. First, intraoperative renal imaging must be mastered. A curvilinear ultrasound probe with a frequency range of 3.5–5 MHz is optimal to provide adequate depth for renal imaging. Any standard ultrasound imaging console can be used. By convention, the ultrasound probe is oriented on the patient’s body such that the upper pole and head side of the patient appears on the left of the screen. Initially, the probe can be placed against the skin parallel to the body axis to identify the location of the kidney and all of the renal anatomy, including the location of calices, the target stone(s), and surrounding viscera. Once the anatomy has been surveyed, rotating the probe so that it is parallel to the ribs can allow for an unobstructed view of the kidney with no intervening rib shadows. In this fashion, the target calyx for entry can be centered toward the left (for upper and mid-kidney entry) or the right (for lower pole entry) of the imaging screen to shorten the distance between the skin and target calyx [47]. Second, control of the needle must be mastered to bring its tip into the target calyx. For free-hand needle control, there are two general approaches—the longitudinal technique, where the needle enters from the top or bottom of the probe, and the transverse technique, where the needle enters from the side of the probe [48]. The transverse technique generally requires more advanced imaging skill given that the needle is only seen in a single cross-section as it is advanced toward the target. The longitudinal technique facilitates the entire trajectory of the needle to be visualized. In either approach, the surgeon should focus on bringing the needle into the target image and not chasing the needle with the ultrasound probe. An ultrasound probe guide can be used to allow the surgeon to focus on the imaging skill set alone [49] though it can sometimes be cumbersome to the user and can interfere with fine needle control. Once learned, these two skills will allow ultrasound-guided renal access to become part of the practitioner's daily armamentarium.

Compared with fluoroscopy, ultrasound for renal access has several advantages. Selection of the optimal calyx of entry is simplified with ultrasound guidance. During fluoroscopy, identification of the posterior calyx in the prone position is critical but can be challenging, as a two-dimensional image must be visualized as a three-dimensional target for success. On an ultrasound image, the calyx that is closest to the top of the screen is usually the optimal target of entry. In the prone position, this is posterior, while in the supine position, it can be anterior. However, compared with fluoroscopy, ultrasound imaging is truly live and continuous, and as long as the target calyx of entry facilitates access to stones with minimal torque on the kidney, its selection will allow for procedural success. In addition, ultrasound allows for visualization and avoidance of perirenal structures, including lungs, bowel, spleen, and liver. Compared with fluoroscopy guidance, it is also associated with decreased exposure to radiation for providers, staff, and patients (including obese patients) [50], lower expense [51], and a much shorter learning curve [52, 54]. The shortened learning curve is a particularly compelling reason to support the use of ultrasound guidance over fluoroscopy. It can take a learner as many as 120 cases to master fluoroscopy guidance [52], whereas as few as 6–20 cases may be required for a surgeon of any level to incorporate ultrasound guidance into their practice [53].

Radiation-Free PCNL (Complete Ultrasound Guidance for PCNL)

Achieving complete ultrasound guidance for PCNL entails adapting instruments used during dilation that are designed primarily for use under fluoroscopy. Wires can be readily visualized as long as they are not hydrophilic in nature. Serial dilators can be visualized as they cover up the echogenic signal of the wire. Localization of the tip of the dilator entails watching for disappearance of the wire signal. The interface between the bright and the lost signal signifies the location of the dilator tip. Balloon dilators generally have a marker at their tip that can be seen under ultrasound imaging, and it has been shown that tract dilation using both a balloon catheter and sequential Amplatz dilators can be safely monitored by ultrasound [54, 55]. With these principles in mind, X-ray-free PCNL using only ultrasound imaging is achievable. The ideal kidneys to enable transitioning toward complete reliance on ultrasound are renal units where there is moderate hydronephrosis and absence of staghorn stone [56]. Complete ultrasound guidance can be achieved in the supine and prone positions with preservation of safe clinical outcomes [57].

Complete ultrasound-guided PCNL has been described as effective and safe in both the supine and the prone position [58].

New Technologies for PCNL Access

Different methods based on new technologies (motion tracking systems, robotics, image processing, and computer graphics) have been developed in recent years in an attempt to ease percutaneous access creation and reduce RE. However, no widely acceptable solution has yet been achieved.

Computerized systems have been tested to improve access by virtually projecting the ultrasound images in real time onto those acquired with fluoroscopy. Such virtual projection was proved to work in vitro but was used in just one patient [59]. Similarly, other technologies such as C-arm CT with a 3D virtual navigation system proved successful in creating the renal access after ultrasound puncture failures but at the expense of high RE [60].

"The Locator" is a navigation system that assists a fluoroscopically guided puncture, stabilizing the needle, and it has been shown to reduce fluoroscopy time in vitro [61]. In an ex vivo model, UroDyna-CT was found to successfully guide the puncture using laser and multiplanar reconstructions of CT scans, but again at the expense of higher RE than is observed with other options [62].

Robotic devices (PAKY, PAKY-RCM, AcuBot, and MrBot) have also been designed to guide the needle more precisely toward the calyx of entry, making it less dependent on the surgeon, using X-ray, MRI or ultrasound [63, 64, 65, 66]. More recently, the ANT-X computer-assisted navigation system was described, which uses automatic robotic needle alignment with manual needle insertion under fluoroscopy and is able to compensate for respiratory motion [67]. Overall, these devices have been shown to achieve adequate access at the expense of high cost and setup complexity.

Rassweiler et al. [68] published their experience with free-hand puncture using X-ray and augmented reality with an iPad (Apple Inc., Cupertino, CA, USA). This technique superimposes the segmented anatomic images from a preoperative CT scan, performed with the patient theoretically in the same position as for PCNL, with the actual image of the patient displayed on the iPad. One of its limitations is that there can be variations in the anatomy on the CT and real-time images as a result of respiratory movements, small differences in patient positioning, or modifications of the anatomy that occur during needle advancement.

Lima et al. [69, 70] have also published their experience with electromagnetic puncture of the collecting system. Using a flexible ureteroscope, a specific catheter is placed into the desired papillary puncture site, which allows a special needle with a sensor on its tip to be placed percutaneously (guided with ultrasound). This is a promising technique. Its limitations are its cost and the impossibility of delivering a flexible ureteroscope to the calyx of entry in some cases.

Future investigations need to focus on options that simplify tract creation and can help in standardizing the procedure, making it less dependent on the surgeon while maintaining its safety and using less or no radiation, at a reasonable cost.

Conclusion A specific preoperative checklist should be used to reduce fluoroscopy time and RE. Low radiation or completely fluoroless endourological procedures have been shown to be effective, feasible, and safe. Urologists should be aware of the risks of RE and should apply ALARA protocols during endourological procedures.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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

References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1. Musolino SV, DeFranco J, Schlueck R. The ALARA principle in the context of a radiological or nuclear emergency. Health Phys. 2008;94:109–11. https://doi.org/10.1097/01.HP.0000285801.87304.3 f.
2. Ngo TC, Macleod LC, Rosenstein DI, Reese JH, Shinghal R. Tracking intraoperative fluoroscopy utilization reduces radiation exposure during ureteroscopy. J Endourol. 2011;25:763–7. https://doi.org/10.1089/end.2010.0624.
3. Arnold DCI, Baldwin DD. Ureteroscopy: indications, instrumentation & technique. Current Clinical Urology, vol. XXII. New York City: Humana Press; 2013.
4. Bagley DH, Cubler-Goodman A. Radiation exposure during ureteroscopy. J Urol. 1999;144:1356–8.
5. Arenas JL, Baldwin DD. Techniques for minimizing radiation exposure during evaluation, surgical treatment, and follow-up of urinary lithiasis. Curr Urol Rep. 2015;16:45.
6. Landauer RS. Application of the inverse-square law to oil-immersed tubes. Radiology. 1947;48:175–7.
7. Norris TG. Radiation safety in fluoroscopy. Radiol Technol. 2002;73:511–33.
8. Nguyen KK, et al. In automated fluoroscopy settings, does shielding affect radiation exposure to surrounding unshielded tissues? J Endourol. 2012;26:1489–93.
9. Elkoushy MA, et al. Pulsed fluoroscopy in ureteroscopy and percutaneous nephrolithotomy. Urology. 2012;79(6):1230–5 Pulsed fluoroscopy resulted in significantly lower fluoroscopy time without affecting surgery time or stone-free rates.
10. Cantlon MB, Ilyas AM. Assessment of radiation protection in hand-shielding products with mini C-arm fluoroscopy. Hand (New York, N,Y) [Internet]. 2019:155894471986593. [cited] Available from. https://doi.org/10.1177/1558944719865937.
11. Kokorowski PJ, Chow JS, Strauss KJ, Pennison M, Tan W, Cilento B, et al. Prospective systematic intervention to reduce patient exposure to radiation during pediatric ureteroscopy. J Urol. 2013;190:1474–8.
12. Hernanz-Schulman M, Goske MJ, Bercha IH, et al. Pause and pulse: ten steps that help manage radiation dose during pediatric fluoroscopy. AJR Am J Roentgenol. 2011;197:475.
13.• Greene DJ, Tenggadjaja CF, Bowman RJ, Agarwal G, Ebrahimi KY, Baldwin DD. Comparison of a reduced radiation fluoroscopy protocol to conventional fluoroscopy during uncomplicated ureteroscopy. Urology. 2011;78(2):286–90. **This is a well described systematic protocol to reduce radiation exposure**.
14. Elkoushy MA, Shahrour W, Andonian S. Pulsed fluoroscopy in ureteroscopy and percutaneous nephrolithotomy. Urology. 2012;79(6):1230–5.
15.•• Hsi RS, Harper JD. Fluoroless ureteroscopy: zero-dose fluoroscopy during ureteroscopic treatment of urinary-tract calculi. J Endourol. 2013;27(4):432–7. **This article shows that a reduced fluoroscopy protocol can resultin minimal fluoroscopy time and radiation exposurebeing safe and feasible in the majority of ureteroscopic cases.**
16. Mohey A, Alhefnawy M, Mahmoud M, Gomaa R, Soliman T, Ahmed S, et al. Fluoroless-ureteroscopy for definitive management of distal ureteral calculi: randomized controlled trial. Can J Urol. 2018;25(1):9205–9.
17.•• Olgin G, Smith D, Alsyouf M, Arenas JL, Engebretsen S, Huang G, Arnold DC and, Baldwin DD. Ureteroscopy without fluoroscopy: a feasibility study and comparison with conventional ureteroscopy. J Endourol 2015;29(6):625–629. **This study demonstrates the feasibility and efficacy of the completely fluoroless ureteroscopic treatment of calculi throughout the entire upper urinary tract.**
18. Çimen HI, Halis F, Sağlam HS, Gökçe A. Fluoroscopy-free technique is safe and feasible in retrograde intrarenal surgery for renal stones. Turk J Urol. 2017;43(2):309–12.
19.•• Manzo BO, Lozada E, Manzo G, Sánchez HM, Gomez F, Figueroa A, et al. Radiation-free flexible ureteroscopy for kidney stone treatment. Arab J Urol. 2019;17(3):200–5. **This study showed how**

fluoroless ureteroscopy is safe and feasable having comparable complications and stone free rates as ureteroscopy with fluoroscopy.
20. Kirac M, Ergin G, Kibar Y, Köprü B, Biri H. The efficacy of ureteroscopy without fluoroscopy for ureteral and renal stones in pediatric patients. J Endourol. 2018;32(2):100–5.
21.•• Emiliani E, Motta GL, Llorens E, Quiroz Y, Kanashiro AK, Angerri O, et al. Totally fluoroless retrograde intrarenal surgery technique in presented patients: tips and tricks. J Pediatr Urol. https://doi.org/10.1016/j.jpurol.2019.06.017. **A study in which all steps and tips and tricks to perform a fluoroless ureteroscopy are well defined.**
22. Boeri L, Gallioli A, De Lorenzis E, Fontana M, Palmisano F, Sampogna G, et al. Impact of surgical experience on radiation exposure during retrograde intrarenal surgery: a propensity-score matching analysis. Eur Urol Focus. 2018. https://doi.org/10.1016/j.euf.2018.08.028.
23. Mandhani A, Chaudhury H, Gupta N, Singh HK, Kapoor R, Kumar A. Is fluoroscopy essential for retrieval of lower ureteric stones? Urol Int [Internet]. 2007;78(1):70–2. [cited 2019 Oct 7];Available from. https://doi.org/10.1159/000096938.
24. Ekici M, Ozgur B, Senturk A, Ekici A, Aydin C, Baykam M. All-seeing-access sheath: a novel fluoroscopy-free placement technique in retrograde intrarenal surgery. J Coll Physicians Surg Pak [Internet]. 2019;29(3):263–7. [cited 2019 Oct 7];Available from:. https://doi.org/10.29271/jcpsp.2019.03.263.
25. Tepeler A, Armagan A, Akman T, Sılay MS, Akçay M, Başıbüyük İ, et al. Is fluoroscopic imaging mandatory for endoscopic treatment of ureteral stones? Urology [Internet]. 2012;80(5):1002–6. [cited 2019 Oct 7];Available from. https://doi.org/10.1016/j.urology.2012.02.082.
26. Peng Y, Xu B, Zhang W, Li L, Liu M, Gao X, et al. Retrograde intrarenal surgery for the treatment of renal stones: is fluoroscopy-free technique achievable? Urolithiasis [Internet]. 2015;43(3):265–70. [cited 2019 Oct 7];Available from. https://doi.org/10.1007/s00240-015-0760-x.
27. Aboutaleb H. Fluoroscopy free flexible ureteroscopy with holmium: Yttrium-aluminum-garnet laser lithotripsy for removal of renal calculi. Arab J Urol [Internet]. 2016;14(2):123–30. [cited 2019 Oct 7];Available from. https://doi.org/10.1016/j.aju.2016.04.004.
28. Firdolaş F, Pirinççi N, Ozan T, Karakeçi A, Orhan İ. Retrograde intrarenal surgery technique without using fluoroscopy and access sheet in the treatment of kidney stones. Turk J Med Sci [Internet]. [cited 2019 Oct 7]. 49(3):821–5.
29. Hein S, Schoenthaler M, Wilhelm K, Schlager D, Vach W, Wetterauer U, et al. Ultralow radiation exposure during flexible ureteroscopy in patients with nephrolithiasis—how far can we go? Urology [Internet]. 2017;108:34–9. [cited 2019 Oct 3];Available from. https://doi.org/10.1016/j.urology.2017.06.016.
30. Uribe CA, Osorio H, Benavides J, Martinez CH, Valley ZA, Kaler KS. A new technique for percutaneous nephrolithotomy using retrograde ureteroscopy and laser fiber to achieve percutaneous nephrostomy access: the initial case report. J Endourol Case Rep. 2019;5(3):131–6.
31. Sönmez MG, Kara C. A new approach in ureteral access sheath locating in retrograde intrarenal surgery (RIRS) by endovisional technique. Arch Ital Urol Androl. n.d.-a;87(4):286. https://doi.org/10.4081/aiua.2015.4.286.
32. Senel C, Tuncel A, Balci M, Asfuroglu A, Aykanat C, Guzel O, et al. Safety and reliability of fluoroscopy-free technique in retrograde intrarenal surgery. Minerva Urol Nefrol. 2018;70(6):606–11.
33.• Sönmez MG, Kara C. A new approach in ureteral access sheath locating in retrograde intrarenal surgery (RIRS) by endovisional technique. Arch Ital Urol Androl. n.d.-b).;87(4):286. **This article reviews a novel technique to locate the sheath safely in patients who has difficulty in ureteral access sheath locating with lower radiation exposure.**
34. Brisbane W, et al. Fluoroless ureteral stent placement following uncomplicated ureteroscopic stone removal: a feasibility study. Urology. 2012;80(4):766–70.
35. St-Laurent MP, Doizi S, Rosec M, Terrasa JB, Villa L, Traxer O, et al. Radiation exposure in prone vs. modified supine position during PCNL: results with an anthropomorphic model. Can Urol Assoc J. 2019;13(8):246–9.
36. Scoffone CM, Cracco CM, Cossu M, Grande S, Poggio M, Scarpa RM. Endoscopic combined intrarenal surgery in Galdakao-modified supine Valdivia position: a new standard for percutaneous nephrolithotomy? Eur Urol. 2008;54(6):1393–403.
37. Grasso M, Lang G, Taylor FC. Flexible ureteroscopically assisted percutaneous renal access. Tech Urol. 1995;1:39–43.
38. Serra S, Corona A, Caddeo G, De Lisa A. The endovision technique in renal percutaneous lithotripsy. Urologia. 2012;79(19):125–7.
39. Lawson RK, Murphy JB, Taylor AJ, Jacobs SC. Retrograde method for percutaneous access to kidney. Urology. 1983;22:580–2.
40. Kawahara T, Ito H, Terao H. Ureteroscopy assisted retrograde nephrostomy: a new technique for percutaneous nephrolithotomy (PCNL). BJU Int. 2012;110(4):558–9.
41. Uribe CA, Osorio H, Benavides J, Martinez CH, Valley ZA, Kaler KS. A new technique for percutaneous nephrolithotomy using retrograde ureteroscopy and laser fiber to achieve percutaneous nephrostomy access: the initial case report. J Endourol Case Rep. 2019;5(3):131–6.
42. Bader MJ, Gratzke C, Seitz M, Sharma R, Stief CG, Desai M. The “all-seeing needle”: initial results of an optical puncture system confirming access in percutaneous nephrolithotomy. Eur Urol. 2011;59:1054–9.
43. Llanes González L, Pérez Fentes DA, Palmero Martí JL. Micropercutaneous nephrolithotomy (micro-PNL or microperc): a new tool in the treatment of renal lithiasis. Arch Esp Urol. 2014;67(3):225–9.
44.•• Andonian S, Scoffone CM, Louie MK, et al. Does imaging modality used for percutaneous renal access make a difference? A matched case analysis. J Endourol. 2013;27:24–8. **This article shows how percutaneous access obtained by ultrasound guidance was safer compared to fluorocopy access.**
45.•• Armitage JN, Withington J, Fowler S, et al. Percutaneous nephrolithotomy access by urologist or interventional radiologist: practice and outcomes in the UK. BJU Int. 2017;119:913–8. **Their findings suggest that favourable PCNL outcomes may be expected where access is obtained by either a urologist interventional radiologist.**
46. Chi T, Masic S, Li J, et al. Ultrasound guidance for renal tract access and dilation reduces radiation exposure during percutaneous nephrolithotomy. Adv Urol. 2016;2016:3840697.
47. Beiko D, Razvi H, Bhojani N, Bjazevic J, Bayne DB, Tzou DT, et al. Techniques – ultrasound-guided percutaneous nephrolithotomy: how we do it. Can Urol Assoc J. 2019. https://doi.org/10.5489/cuaj.6076.
48. Chu C, Masic S, Usawachintachit M, et al. Ultrasound-guided renal access for percutaneous nephrolithotomy: a description of three novel ultrasound-guided needle techniques. J Endourol. 2016;30:153–8.
49. Osman M, Wendt-Nordahl G, Heger K, et al. Percutaneous nephrolithotomy with ultrasonography-guided renal access: experience from over 300 cases. BJU Int. 2005;96:875–8.
50. Usawachintachit M, Masic S, Chang HC, et al. Ultrasound guidance to assist percutaneous nephrolithotomy reduces radiation exposure in obese patients. Urology. 2016;98:32–8.
51. Hudnall M, Usawachintachit M, Metzler I, Tzou DT, Harrison B, Lobo E, et al. Ultrasound guidance reduces percutaneous

nephrolithotomy cost compared to fluoroscopy. Urology. 2017;103:52–8.
52. Tanriverdi O, Boylu U, Kendirci M, et al. The learning curve in the training of percutaneous nephrolithotomy. Eur Urol. 2007;52:206–11.
53. Usawachintachit M, Masic S, Allen IE, Li J, Chi T. Adopting ultrasound guidance for prone percutaneous nephrolithotomy: evaluating the learning curve for the experienced surgeon. J Endourol. 2016;30(8):856–63.
54. Wang S, Zhang Y, Zhang X, Tang Y, Xiao B, Hu W, et al. Tract dilation monitored by ultrasound in percutaneous nephrolithotomy: feasible and safe. World J Urol. 2019. https://doi.org/10.1007/s00345-019-02876-7.
55. Zhou T, Chen G, Gao X, Zhang W, Xu C, Li L, et al. 'X-ray'-free balloon dilation for totally ultrasound-guided percutaneous nephrolithotomy. Urolithiasis. 2015;43(2):189–95.
56. Usawachintachit M, Tzou DT, Hu W, et al. X-ray free ultrasound-guided percutaneous nephrolithotomy: how to select the right patient? Urology. 2016;100:38–44.
57. Armas-Phan M, Tzou DT, Bayne DB, et al. Ultrasound guidance can be used safely for renal tract dilation during percutaneous nephrolithotomy. BJU Int. 2020;125(2):284–291.
58. El-Shaer W, Kandeel W, Abdel-Lateef S, Torky A, Elshaer A. Complete ultrasound-guided percutaneous nephrolithotomy in prone and supine positions: a randomized controlled study. Urology. 2019;128:31–7.
59. Mozer P, Conort P, Leroy A, et al. Aid to percutaneous renal access by virtual projection of the ultrasound puncture tract onto fluoroscopic images. J Endourol. 2007;21(5):460–5.
60. Jiao D, Zhang Z, Sun Z, et al. Percutaneous nephrolithotripsy: C-arm CT with 3D virtual navigation in non-dilated renal collecting systems. Diagn Interv Radiol. 2018;24(1):17–22.
61. Lazarus J, Williams J. The Locator: novel percutaneous nephrolithotomy apparatus to aid collecting system puncture: a preliminary report. J Endourol. 2011;25(5):747–50.
62. 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(5):1147–51.
63. Caddedu JA, Stoianovici D, Chen RN, et al. Stereotactic mechanical percutaneous renal access. J Endourol. 1998;12:121–5.
64. Su LM, Stoianovici D, Jarret TW, et al. Robotic percutaneous access to the kidney: comparison with standard manual Access. J Endourol. 2002;16(7):417–5.
65. Mozer P, Troccaz J, Stoianovici D. Urologic robots and future directions. Curr Opin Urol. 2009;19:114–9.
66. Rodrigues PL, Rodrigues NF, Fonseca J, Lima E, Vilaça JL. Kidney targeting and puncturing during percutaneous nephrolithotomy: recent advances and future perspectives. J Endourol. 2013;27(7):826–34.
67. Oo MM, Gandhi HR, Chong KT, et al. Automated needle targeting with x-ray (ANT-X) - Robot-assisted device for percutaneous nephrolithotomy (PCNL) with its first successful use in human. J Endourol. 2018. https://doi.org/10.1089/end.2018.0003.
68. Rassweiler JJ, Müller M, Fangerau M, et al. iPAD-assisted percutaneous access to the kidney using marker-based navigation: initial clinical experience. Eur Urol. 2012;61(3):628–3.
69. Huber J, Wegner I, Meinzer HP, et al. Navigated renal access using electromagnetic tracking: an initial experience. Surg Endosc. 2011;25:1307–12.
70. Lima E, Rodrigues PL, Mota P, et al. Ureteroscopy assisted percutaneous kidney access made easy: first clinical experience with a novel navigation system using electromagnetic guidance (IDEAL Stage1). Eur Urol. 2017;72(4):610–6.