New technology in ureteroscopy and percutaneous nephrolithotomy

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Purpose of review

New developments of retrograde intrarenal and percutaneous endoscopic surgery for nephrolithiasis have significantly enhanced the indications of endourology compared to extracorporeal shock wave lithotripsy. We want to review the most significant new technologies

Recent findings

New technology to access the renal collecting system includes marker-based tracking with iPAD, laser-guided puncture on (Uro)Dyna-CT, electromagnetic tracking (only experimental), and optical tracking for ultrasound-guided puncture. Miniaturization percutaneous nephrolithotomy has been further extended and classified to Midi-PCNL (20-22F/L), Mini-PCNL (16-18F/M), Ultra/Super-mini-PCNL (12-14F/S), and Micro-PCNL (8-10F/XS). Knowledge of Ho:YAG-laser lithotripsy including power settings for fragmentation (depending on stone composition), dusting (0.5J/20Hz), and popcorn-effect/laser-burst (1J/30Hz) becomes mandatory. Also hydrodynamic mechanisms for retrieval of fragments (active/passive washout, purging, vacuum-cleaner-effect) have gained importance. Improvements of FURS focus on digital-HD-video-technology with post-processing software (NBI/SPIES) providing better resolution and increased optical field, further miniaturization of endoscopes to fit in smaller access sheath (12/14F), additional tip-less Nitinol baskets and graspers, and introduction of a robotic device (Avicenna Roboflex) to improve ergonomics of the procedure.

Summary

Based on recent technical developments, percutaneous nephrolithotomy and particularly flexible ureteroscopy will further gain preference in management of urolithiasis compared to ESWL. Endourology may offer a higher rate of primary success with minimal side-effects which could weigh out the slightly higher degree of invasiveness.

Keywords

three-dimensional computer tomography, laser lithotripsy, miniaturized percutaneous nephrolithotomy, navigation, robotic flexible ureteroscopy, stone disintegration, virtual reality

INTRODUCTION

Recent technological developments in endo-urology lead to dramatic changes in management of urolithiasis. Extracorporeal shock wave lithotripsy (ESWL) is still considered first-line treatment for renal stones up to 1–2 cm and most radioopaque ureteral calculi. However, a consistent trend favors endourology [1,2]. New technology included image-guided navigation to access the renal collecting system, miniaturization of instruments, improvement of laser lithotripters, and robot-assisted flexible ureteroscopy. We focus on these developments based on literature research, a recent expert meeting of European association of Urology (EAU)-section of Urotechnology in collaboration with EAU-section of Urolithiasis, and personal experience.

MATERIAL AND METHODS

A literature research was performed in *Medline/PubMed* from 2012 to 2015 using keywords 'minipercutaneous nephrolithotomy ($n=39$)', 'miniaturized percutaneous nephrolithotomy ($N=15$)', 'micro percutaneous nephrolithotomy ($n=40$)', 'robotic flexible ureteroscopy ($n=13$)', 'endourology ergonomics

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KEY POINTS

- Intra-operative navigation can be helpful for percutaneous puncture of collecting system prior to PCNL.
- Miniaturization of PCNL can reduce the access trauma and is useful for stones less than 2 cm.
- The proposed classification of armamentarium used for PCNL is very useful.
- Adequate knowledge about hydrodynamics of fragment retrieval becomes crucial.
- Laser lithotripsy includes new concepts like dusting or using ‘popcorn-effect’ (laser bursts).
- Digital HD-video-technology will become the standard for FURS.
- Robotic FURS significantly improves ergonomics of FURS.

($n=8$)’, ‘laser-induced intracorporeal lithotripsy ($n=15$)’, ‘laser lithotripsy urinary ($n=198$)’, ‘flexible ureteroscopy ($n=200$)’. Additionally, an Internet-research (web, figures, and videos) was accomplished to be able to pick up all relevant novelties in endourologic stone surgery.

PERCUTANEOUS NEPHROLITHOTOMY

Navigated puncturing of collecting system

Exact access to renal collecting system is most important for success of (percutaneous nephrolithotomy) PCNL traditionally this can be accomplished by use of fluoroscopy, ultrasound, or combination of both [3–5]. The puncture should be associated with minimal bleeding and offer optimal access to the collecting system to remove maximal stone burden. New puncture techniques [6–13,14■,15■■] [(www.clearguidemedical.com/news) 30 August 2015] use other modalities like multislice computed tomography (CT) for imaging of renal anatomy or apply recent fluoroscopic technologies for navigated puncture (Table 1).

iPAD-assisted puncture

iPAD-assisted access applies marker-based tracking for puncture of collecting system (Fig. 1a). Preoperatively, a multislice CT is performed in prone position on PCNL-cushion with six colored radiopaque markers on the skin around the target area [8,9]. CT-data are transferred to a special open software (Medical Imaging Interaction Toolkit), creating three-dimensional-images based on segmentation of interesting structures (kidney, collecting system, ribs, bowel, liver, and spleen).

During PCNL, patient lies in same prone position. The iPAD is used as camera, computer, and display. Data transfer to central server/laptop is based on Wi-Fi. When virtual and real markers overlap, virtual anatomy displayed on iPAD correlates with real anatomy and can be used for puncture. Two-dimensional digital fluoroscopy serves as real-time imaging mode (Fig. 1b).

Based on experimental studies feasibility was tested in three patients followed by a comparative matched-pair analysis (Table 1). We could demonstrate safety and efficacy of the technique based on an Idea, Development, Exploration, Assessment, Long-term results-approach, however, no significant improvement considering puncture time or radiation exposure. Future improvements are necessary and may include tracking of puncture needle respectively in combination with other tracking/localization modalities [15■■].

Table 1. Comparison of new techniques to puncture the renal collecting system compared with standard technique

Technique	Puncture time (min)	Number of punctures	Study design
PAKY [6]	10.4 ± 6.5	2.2 ± 1.6	Clinical PCNL
EMT [7]	0.3 (0.2–0.74)	2	Porcine kidney (*in vivo*)
Acubot [8]	0.6 (0.2–1.3)	n.a.	Kidney-model
Dyna-CT [13]	4.6 (2–10.2)	1	Puncture model
Dyna-CT [14■]	1.0 (0.5–1.5)	1.3 (1–3)	Clinical PCNL
iPAD [10]	1.6 (0.2–9.0)	2 (1–6)	Kidney model
iPAD^{+}	4.38 (0.58–20)	1.9 (1–4)	Clinical PCNL
US/Fluoro^{+}	1.78 (0.75–5.18)	1.3 (1–2)	Clinical PCNL

PAKY, percutaneous access of the kidney robot; PCNL, percutaneous nephrolithotomy; n.a., not available.
$^{+}$Present study.

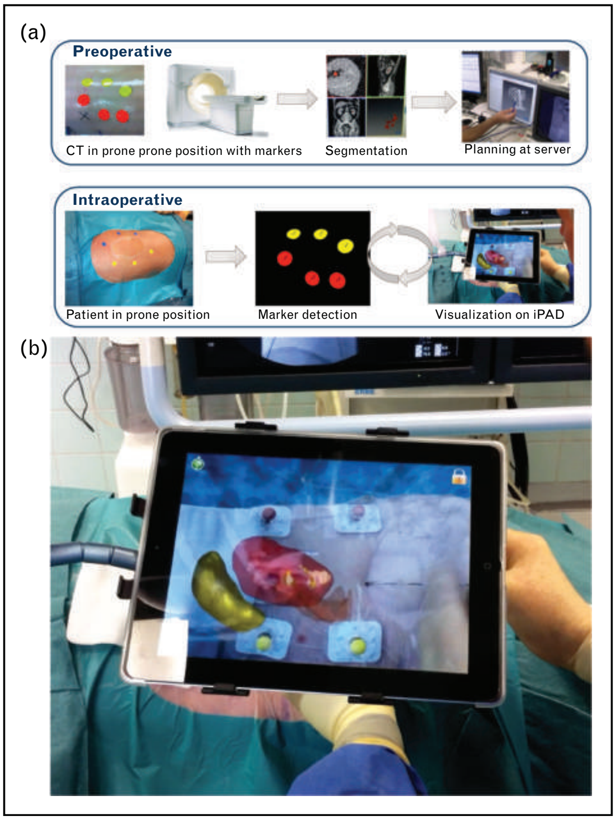

FIGURE 1. Marker-based iPAD-assisted puncture of renal collecting system prior to percutaneous nephrolithotomy; Algorithm: preoperative computed tomography with patient in prone position and markers on skin; segmentation of relevant structures and planning; positioning of patient on PCNL-cushion; marker detection by Medical Imaging Interaction Toolkit and visualization of virtual anatomy on iPAD. Puncture of the kidney with iPAD-assistance. iPAD fixed on dedicated arm. Verification of successful puncture by fluoroscopy. PCNL, percutaneous nephrolithotomy.

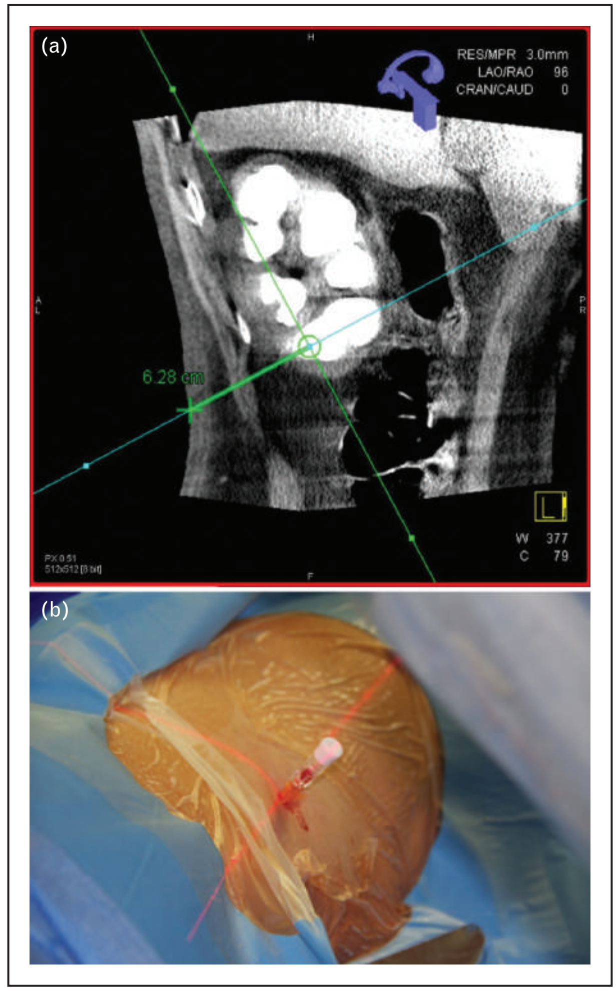

FIGURE 2. Laser-guided puncture of renal collecting system with (Uro)Dyna-CT, (Uro)Dyna-computed tomography-segmented images of stone-bearing kidney, three-dimensional demonstration of collecting system and determination of puncture line. Laser cross indicates the point of needle insertion according to bull's eye view.

Dyna computed tomography for three-dimensional-computed tomography-guided puncture

(Uro-)Dyna-CT (Siemens Medical Solutions, Erlangen, Germany) represents a digital angiography unit, which can be rotated around the patient thereby creating an image similar to CT. Segmentation of data allows three-dimensional reconstruction of target structures (Fig. 2a). Special software (Artis Zee Ceiling) enables multiplanar reconstructions. Based on 'bull's eye'-technology, a laser light (syngo iGuide) simulates the puncture line (Fig. 2b). This road map is provided in any position of the C-arm that might be necessary during puncture. Following experimental studies this technology was tested in a pilot study (Table 1) [13,14▪]. Image acquisition uses higher radiation doses than standard fluoroscopy. However, being in an acceptable range compared with alternative procedures (CT-guided punctures with multislice-CT) used for complex cases.

Electromagnetic tracking for puncture

Electromagnetic tracking (EMT) uses a magnetic field generated around the patient to measure position of ferromagnetic structures inside the body. For percutaneous access to renal collecting system a sensor coil attached to tip of ureteral catheter is used [11,12]. EMT may be interfered by ferromagnetic objects like surgical table, instruments, or electrical powered devices [8,15▪▪]. A real-time EMT system (Aurora, NDI, Waterloo, Canada) displays all relevant structures on the screen (Fig. 3 only online). Until now, the system has been used only experimentally (Table 1).

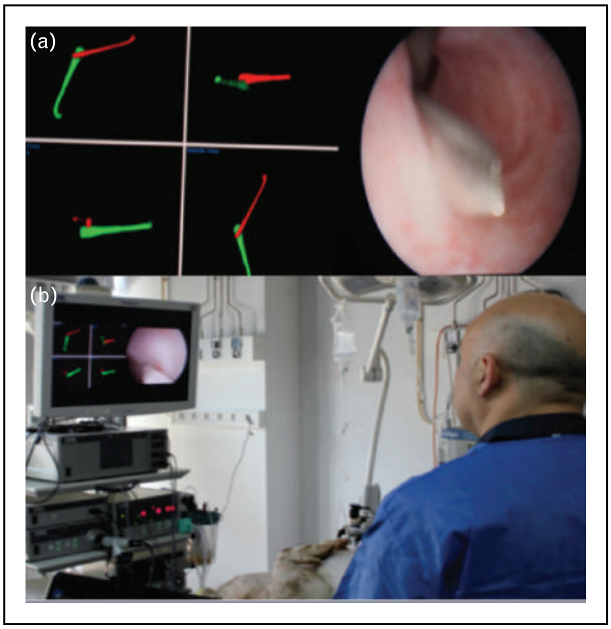

FIGURE 3. Electromagnetic tracking used for puncturing of the renal collecting system. Control of needle on double display showing position of needle (red) and ureteral catheter with electromagnetic sensor (green) in three dimensions. Videoendoscopic verification of successful puncture.

EMT-tracking does not visualize anatomical structures. Therefore, clinically it might be used only in combination with imaging modalities [15▪▪].

Optical tracking for ultrasound-guided puncture

In 2014, Clearguide One (Clearguide-medical, Baltimore, USA) got US Food and Drug Administration approval as an optical tracking device to enable easy ultrasound-guided punctures (Fig. 4) [(www.clearguidemedical.com/news) 30 August 2015]. The company is a Johns–Hopkins University spin-off, trying to commercialize products of previous projects [7,8]. Until now, there are no publications in urology.

Miniaturization of armamentarium

Initially, small caliber instruments for PCNL were used for special indications (urolithiasis in children, stones in diverticula) using modified short ureteroscopes. Thereafter, minipercutaneous nephrolithotomy was introduced as 'new' treatment concept to minimize access trauma without decreasing efficiency [16,17]. During the last years the concept of miniaturizing instruments has been further extended [16–18,19▪▪,20▪,21,22,23▪▪,24–28,29▪]. Two factors contributed to this paradigm shift: improvement of ultrasound and Holmium-YAG-laser lithotripters; new knowledge about stone fragmentation; and new insights in hydrodynamics of irrigation and shaft for clearance of fragments. For better definition of various instrument sizes a classification has been proposed (Table 2) [29▪].

FIGURE 4. Optical tracking of ultrasound-guided puncture on phantom model. Two infrared sensors determine the position of the ultrasound probe and display the respective puncture line on ultrasound monitor.

Midipercutaneous nephrolithotomy (L, 20–22 F)

Classical sizes of percutaneous shafts include 26–28 F with Amplatz-shaft of 30 F (XL) [4,5]. Improved ultrasound lithotripters using smaller probes with increased transducer frequencies (23.3–26.4 Hz) allowed reduction of instrument size to 21 F still enabling simultaneous aspirations [18]. Thus, size and number of fragments to be extracted is not important (Fig. 5 – only online). In our hands, Midi-PCNL is effective for stones 1.5–3.0 cm in diameter obviating use of larger instruments in most instances. A new approach with similar shaft-size (21 F) represents minimally invasive percutaneous litholapaxy-concept [20▪]. Here Holmium-YAG-laser is used for complete stone disintegration. Shaft design should enable optimal flushout of fragments based on recent hydrodynamic studies [20▪,23▪▪,24].

Minipercutaneous nephrolithotomy (M, 16–18 F)

The concept of miniaturized PCNL originally used such diameters [16,17,19▪▪,21]. Nowadays, various modifications exist: Amplatz-shaft-like metal sheath (Fig. 6a – only online), adaptable sizes of shaft for patients, or video-technology [18,19▪▪,22]. Minipercutaneous nephrolithotomy relies on efficacy of

Table 2. New proposal for nomenclature in percutaneous nephrolithotomy

PCNL-technique	Outer sheath caliber (F)	Inner area (mm^2)	Acronym	Irrigation	Comment
Conventional [3–5]	24–30	59	XL	Closed/open Continuous flow	Optional use of Amplatz sheath
Midi[+]	20–22	38	L	Closed/open	Smaller US-probe (3.7 mm)
Mini/MIP [16–18,19▪▪,20▪,21]	16–18	25	M	Closed/open Continuous flow	Holmium-YAG-laser (0.4 mm)
Ultra-mini (UMP/SMP) [26,27]	11–14	12.5	S	Closed/open	Holmium-YAG-laser (0.4 mm)
Micro [28]	8–10	7	XS	Closed	Holmium-YAG-laser (0.2 mm)

PCNL, percutaneous nephrolithotomy; SMP, super-minipercutaneous nephrolithotomy. [+]Present study Adapted with permission from [28].

Ho-YAG-laser lithotripsy together with the Bernouilli-(Vacuum cleaner)-effect (Fig. 6b only online) to flush out fragments due to increased flow velocity inside the small tube. Although less invasiveness of minipercutaneous nephrolithotomy has not been clearly documented, it is usually related to less blood loss and shorter hospital stay with similar stone-free rates as classical PCNL [21,22,25].

Ultra-minipercutaneous nephrolithotomy (S, 11–14 F)

Ultra-minipercutaneous nephrolithotomy represents next step of miniaturization (Fig. 7 – only online) [26]. The system consists of a small 6 F-working sheath with a three-channel working element (ultra-thin 1 mm telescope, irrigation, 365 μ-laser fiber). ultra-mini percutaneous nephrolithotomy (UMP) must rely on complete laser-induced disintegration, as there is only minimal outflow via the shaft. UMP still enables to flush out fragments by whirlpool effect: the telescope is withdrawn and saline is injected via a side port of shaft to create fluid jets [20▪]. Thus, a high pressure zone is created in a small area and fragments will automatically start escaping from the low-pressure zone. UMP may not require percutaneous nephrostomy (i.e., tubeless). The concept of super-minipercutaneous nephrolithotomy using 7 F nephroscope and a modified 10–14 F access sheath with suction-evacuation function is similar to UMP [27].

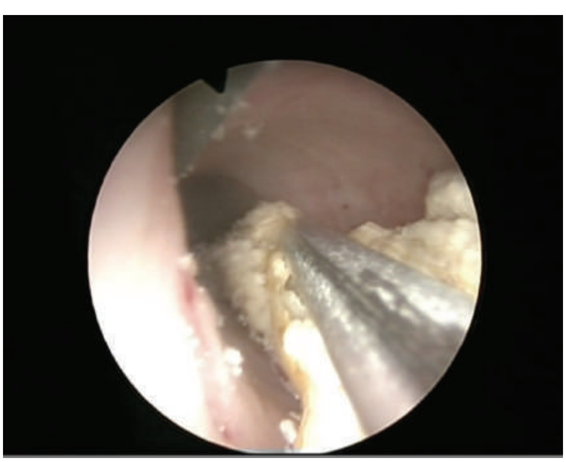

FIGURE 5. Midipercutaneous nephrolithotomy (L). Excellent endoscopic view (HD-Image One, Karl Storz) of 2.4 mm-(8F)-ultrasonic lithotripsy using 21 F nephroscope (Richard Wolf).

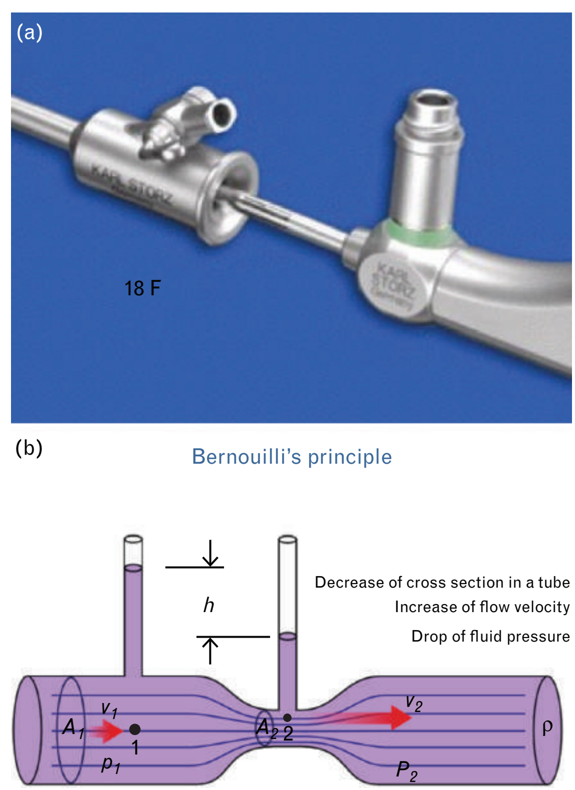

FIGURE 6. Minipercutaneous nephrolithotomy (M). 18F-Amplatz-sheath and nephroscope (Karl Storz), Scheme of Bernouilli's principle as physical basis of vacuum-cleaner effect.

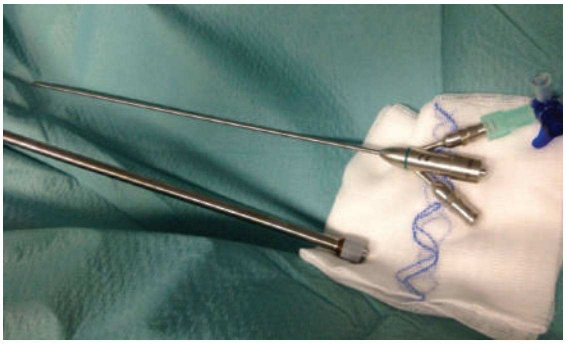

FIGURE 7. Ultra-minipercutaneous nephrolithotomy (X). UMP-device with 14F-outer sheath enabling separate irrigation and 6 F working sheath with ultrathin 1mm-endoscope and two working channels for irrigation and 365 μ-laser fiber.

Micropercutaneous nephrolithotomy (XS, 8–10 F)

Micro-PCNL consists of a 4 F needle bearing a micro-optic, and an 8–10 F sheath enabling navigation into the kidney, respectively Holmium-YAG-laser lithotripsy without needle bending (Fig. 8a only online) [28]. Arrangement of the three channels is comparable to UMP (irrigation, micro optic, 200–230 μ-laser fiber). A dedicated arm stabilizes the camera. Based on 15 patients, Desai concluded, that Microperc would be of interest in selected cases (stone in caliceal diverticulum, ectopic kidney, small lower calyx stone) as alternative to ESWL. In the meantime calculi up to 2 cm have been successfully treated [28]. Own experiences, confirmed effective puncture with all-seeing needle and well tolerated sheath manipulation inside the kidney (Fig. 8b only online). However, irrigation is poor, requiring bloodless puncture for effective laser lithotripsy. Image quality of micro-optic is significantly worse than all alternatives (Fig. 8c only online).

Tubeless percutaneous nephrolithotomy

Tubeless PCNL was introduced in the last century [30]. Nowadays, it has become clinical routine being established in EAU and American Urological Association guidelines [31]. However, there are a variety of modifications including antegrade Double J (DJ)-placement, leaving ureteral catheter in place, removing everything (stentless, tubeless), leaving a DJ-stent with a suture externalized via the access tract for stent removal [18,19▪▪,32]. Additionally, various sealants have been tested for tract closure. However, there are no randomized studies, which could prove any advantage in favor of sealants [18].

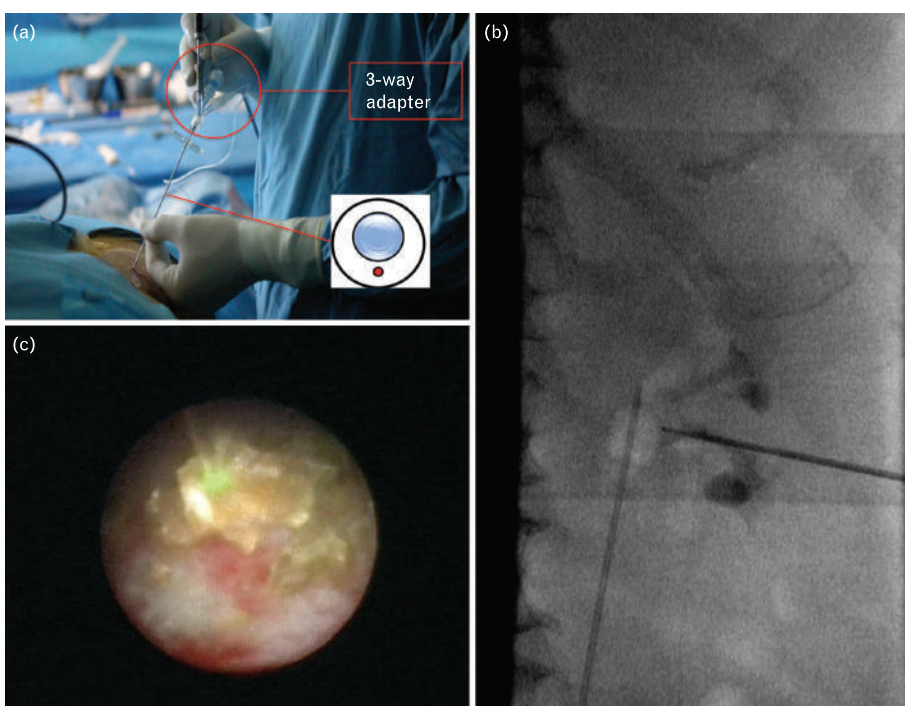

FIGURE 8. Micropercutaneous nephrolithotomy (S). A 4F needle with a micro-optic inside. 8/10 F sheaths allow manipulation inside the kidney. Three-way-adapter for irrigation and 230 μ-laser fiber. Combined ultrasound-fliuorsocopic guided puncture of renal collecting system and endoscopic manipulation of device to pelvic stone. Endoscopic view during laser lithotripsy.

Hydrodynamic background of percutaneous nephrolithotomy

Smaller access diameters combined with laser lithotripsy lead to an increased number of harvested fragments. Dealing with rapidly expanding number of small fragments, respectively, dust induced a shift from mechanical devices to hydrodynamic effects for stone retrieval [20▪]. Several principles of hydrodynamic-aided fragment retrieval can be distinguished: passive washout is defined as stone clearance by transportation based on ureteral peristalsis.

Active washout could be used in several ways: by transportation of fragments within continuous irrigation backflow through access sheath alongside the scope; by filling of collecting system with high pressure and quickly remove the scope resulting in immediate inversion of irrigation flow and pressure with spillage-like removal of stones via the access sheath [27]; by sweeping fragments down the ureter; or by irrigation with a syringe via an additional channel of access sheath [26].

Purging effect means fragment transportation by pressure-controlled irrigation using inflow via percutaneous access and outflow through a Mono-J-catheter or access sheath. Advantage of purging effect includes relatively high irrigation fluid-turnover and fragment transportation without excess of intrarenal pressure [20▪].

Vacuum cleaner effect leads to directed trapping of fragments in a hydrodynamic pseudocavity in front of the scope in a low-pressure situation. The difference to other hydrodynamic stone retrieval effects represents active trapping of fragments. Vacuum cleaner effect is based on Bernouilli‘s principle (Fig. 6b) mimicking a mechanical forceps like an invisible grasper and cannot be seen as a simple wash-out-phenomenon. In larger scopes there is no cavity with low-fluid movement explaining why vacuum cleaner effect does not occur in higher sheath diameters [23▪▪].

To reduce stone removal time and increase primary stone-free rate, endourologists must be aware of the above-mentioned hydrodynamic effects. Further technical innovations such as Lith-Assist – a 11.6F-device for laser lithotripsy with simultaneous suction could be helpful, but need further miniaturization [33].

FLEXIBLE URETERORENOSCOPY

Digital endoscopes

Equally, there has been a significant change regarding quality of flexible ureteroscopes and extension of indications [34]. Introduction of small-caliber digital flexible endoscopes (F 8–9, Olympus URF-V2, Storz Flex XC) provides excellent image with increased resolution and field. Digital technology enables postprocessing of image (Storz Professional Image Enhancement System, narrow band imaging), which can be used for diagnosis of upper tract tumors, but also for calculi (Fig. 9 only online) [35▪▪]. Recently a two-channel-endoscope is available with digital technology (Cobra-HD, Richard Wolf) [36].

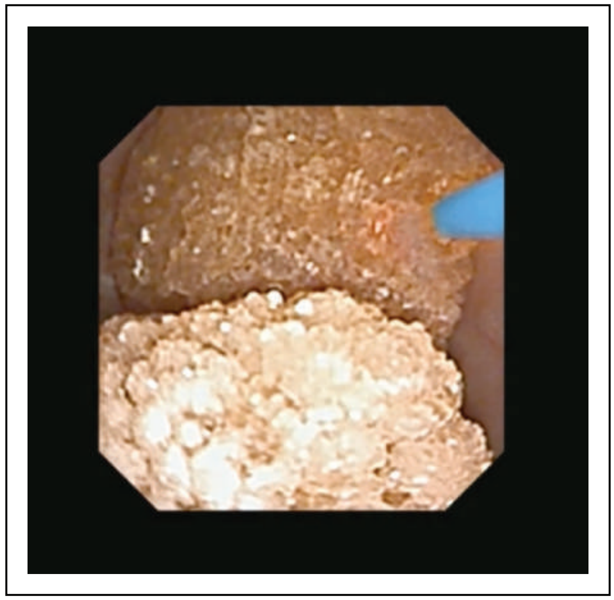

FIGURE 9. Image enhancement using SPIES (Storz Professional Image Enhancement System; Clara + Chroma) during FURS with digital flexible ureteroscope (Karl Storz Flex XC) to optimize visualization of pelvic stone (uric acid).

Access sheath

Success of hydrophilic guidewires stimulated introduction of hydrophilic access sheath in different length and sizes. Whereas, initially only Flex XC (Karl Storz, Tuttlingen, Germany) was able to pass via a 12/14 F access sheath (i.e., Flexor, Cook-Europe), now most digital devices can be introduced. Ideally, access sheath is placed 2 cm below ureteropelvic junction not to interfere with deflection-mechanism of scope (Fig. 10a and b – only online). Even 12/14 F access sheaths allow retrieval of fragments up to 3.5 mm. There are reports of injury due to primary use of access sheath in up to 45% (grade A-lesion) [37▪,38]. Therefore, we prefer presenting of our (robotic) flexible ureterorenoscopy (FURS)-patients. With this concept injury rates can be neglected.

Improved baskets

Nitinol tip-less Dormia-baskets are available from several companies [38]. In our hand the NGage

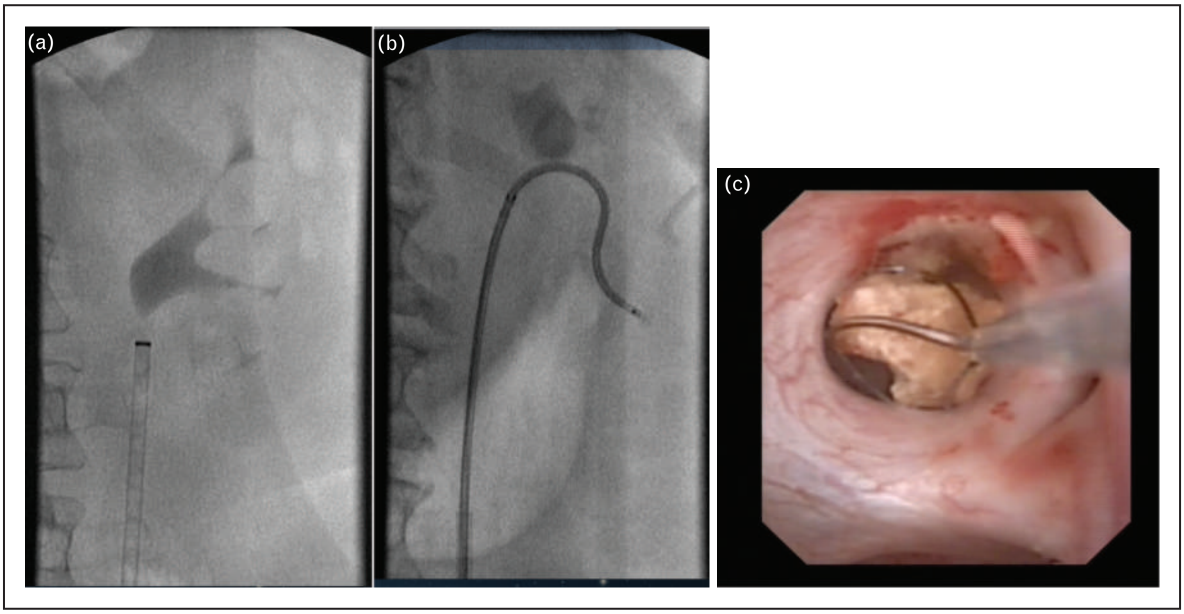

FIGURE 10. Robot-assisted flexible ureterorenoscopy – use of tipless devices, Adequate placement of 12/14 access sheath 2 cm below uretero-pelvic junction to provide optimal deflection of ureteroscope. Access to lower calix by use of Avicenna Roboflex Retrieval of larger fragments using NGage nitinol extracting device (Cook).

extracting device (Cook-Europe, Ireland) acting like a grasper, which can be opened in case of problems proved to be helpful for retrieval of larger fragments (Fig. 10c only online).

Theories of effective laser lithotripsy

Holmium-YAG laser lithotripsy represents gold standard for rigid and flexible URS as for miniaturized PCNL. However, optimal laser lithotripter settings and most appropriate laser fibers have not yet been defined [39▪].

Physics of Holmium-YAG-laser lithotripsy

In previously used laser lithotripters (i.e., dye-laser, neodym-YAG-laser) stone fragmentation was based on intracorporeal shock wave lithotripsy: laser pulse duration of less than 10 μs induced plasma bubbles. When these collapse, cavitation bubbles produce shock waves to break the stone [40,41]. Holmium-YAG-lasers disintegrate stones based on a photothermal effect: laser pulse duration of 100–1000 μs induce temperature rise inside the stone. Holmium-laser radiation is absorbed by residual water in the stone creating vapor pressure breaking the stone from inside. Holmium laser pulse is much too long and cavitation by far too weak to contribute primarily to fragmentation process [41].

Laser lithotripters allow controlling main parameters like pulse energy (J) and pulse frequency (Hz), and total power output (W) as product both. According to adjustment of these parameters, energy intensity delivered at tip of laser fiber is regulated. In 1999, Spore *et al.* [42] tried to determine optimal power setting using an in-vitro model of human calculi. Ablation speed correlated with average power for all types of calculi: struvite stones being the softest calculi, followed by calcium-oxalate-dihydrate, uric acid, calcium-oxalate-monohydrate, and cystine stones. In recent experiments using plaster of Paris, disintegrative efficiency correlated only with pulse energy and not with applied total power [43].

Stone dusting

Apart from ablation speed and disintegrative efficiency, there are other important factors of laser lithotripsy. In the ureter, ‘smash & go’ concepts have been replaced by fragmenting the calculus into a few extractable pieces. However, in the kidney due to increased indications of FURS toward lager stones, this concept requires multiple passages for stone extraction via the access sheath [34,39▪]. Therefore, other strategies like dusting, fine fragmentation or the use of ‘popcorn-effect’ have been introduced [39▪].

Holmium-YAG-lithotripsy requires direct contact of fiber to the stone, which may become cumbersome and time-consuming when the stone breaks early. The concept of dusting aims at fine-fragmentation of calculi around their surface without disintegration. This can be achieved by

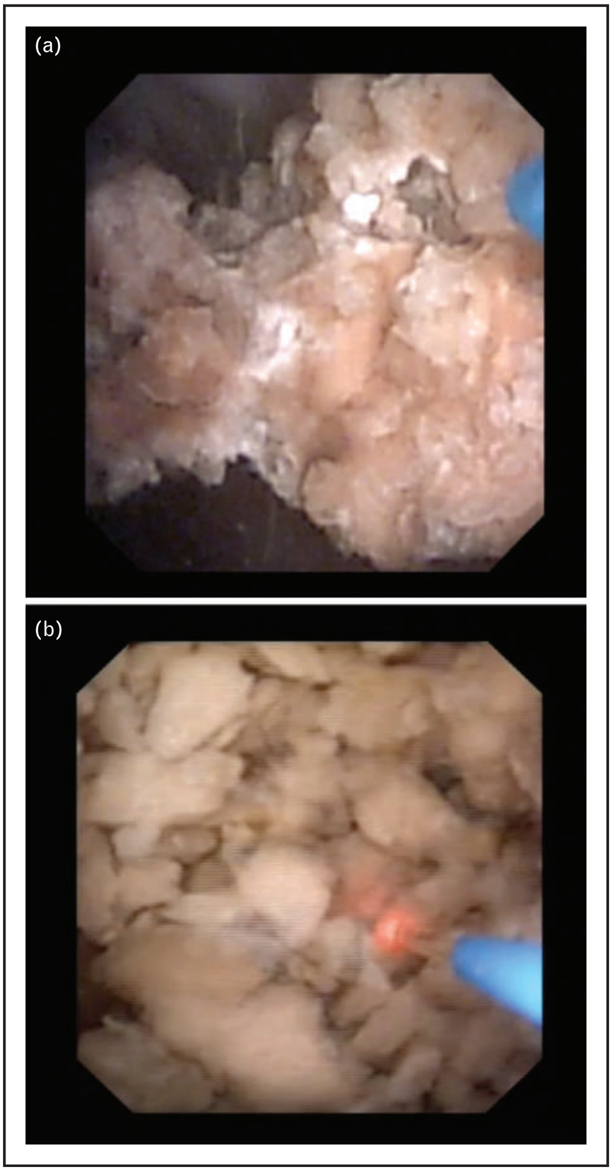

FIGURE 11. Robot-assisted flexible ureterorenoscopy – application of different concepts of stone fragmentation, dusting of large pelvic stone, 'painting' of stone surface with laser fiber and low power high frequency setting (0.5 J, 20 Hz), popcorn-effect (laser burst) to disintegrate multiple larger fragments with medium power high frequency setting (1J, 30 Hz).

'painting' fiber-movements over stone surface using photothermal laser effects (Fig. 11a).

There is a debate about fragment size resulting from different lithotripter settings. According to others and own experiences low-pulse energy in combination with high frequencies (i.e., 0.5J/20–40 Hz) produces smaller stone fragments ('dusting effect') than high-pulse energies [39▪,42,43,44▪▪]. Fragment size may also depend on surgical techniques employed: whether the stone is repeatedly perforated, chipped, and fragmented or only 'painted' with the laser fiber [39▪]. Another advantage of low power setting includes minimal trauma to mucosa when eventually in contact (Fig. 11a).

Popcorn effect

When stone burden is still significant, but pieces are smaller, firing the laser in a noncontact fashion results in a whirlpool-like phenomenon independent of irrigation (Fig. 11b). As it resembles kernels of corn flying about in a popcorn machine, this was called 'popcorn effect' [45]. This phenomenon is not completely understood. Movement of fragments may be caused by a shockwave-induced collapse of vapor or cavitation bubbles ('Moses effect'): distributed acoustic energy throughout the medium leads to contact of fragments with the fiber during pulse emission inducing photothermal ablation. The 'popcorn- effect' should be frequency dependent. In-vitro experiments could verify this only for 1,5 J, whereas at 1 J, a frequency of 40 Hz was less effective than 30 Hz [45]. The phenomenon is similar to high-frequency application of shock waves (burst) and, therefore, should be better called 'laser bursts' [46,47].

Modification of pulse mode

Holmium-YAG-devices providing modification of pulse duration between 150 and 1500 μs compared with 350 and 700 μs in older systems are on the market. Subjective impressions indicated that longer pulses create smaller fragments. However, a recent in-vitro study using hard BegoStones, verified this observation only for a single setting (365 μm fiber, 1 J 10 Hz); for all other settings (i.e., 200 μm, 0.5 J, 20 Hz), there was no difference [48].

Modifications of laser fiber

Spore *et al.* discussed problems of degradation of laser fibers, particularly when using small diameters (200–270 μm). Degree of degradation differed with stone composition being highest for calcium-oxalate-monohydrate [41]. Stripping and cleaving methods could also have a negative impact on laser performance. A recent in-vitro study revealed better lithotripsy performance by coated fibers. Cleaving methods had no impact [49▪].

Laser-induced heat production

As Holmium-laser lithotripsy is photothermal, heat production is discussed as a potential risk factor particular when applying high power settings.

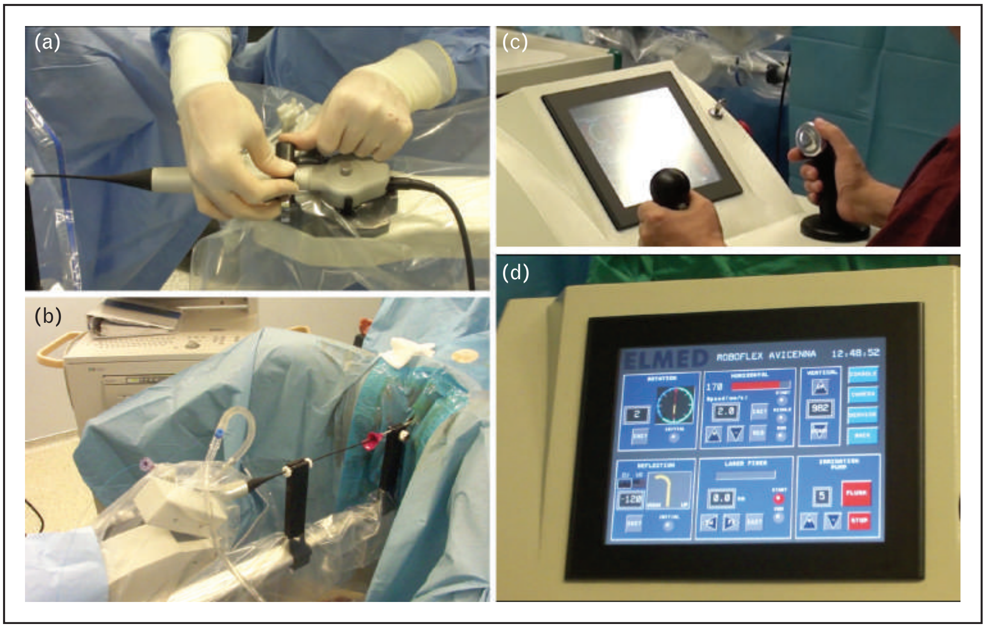

FIGURE 12. Robot-assisted flexible ureterorenoscopy – Avicenna Roboflex, Manipulator with holders for three different digital ureteroscopes (Karl Storz Flex XC, Olympus URF-V2; Wolf Cobra-HD). Endoscope and access sheath are fixed by two stabilizers. Manipulator in orthogonal position for insertion of instrument like the manually guided FURS. No laser fiber should be preinserted. Console with panel and two joy sticks for manipulation. Left hand for 420° rotation and insertion/retraction; right hand with wheel for graduated deflection. Control panel with touch screen to monitor position of endoscope and activate irrigation and control laser-fiber. FURS, flexible ureterorenoscopy.

Table 3. Robot-assisted flexible ureteroscopy with Avicenna Roboflex – Heilbronn Experience (October 2014–August 2015)

Criteria	Patients' data	Comment
No. of patients	90; men 31, women 59	
Age (years)	56 (25–76)	No children
BMI	29.1 (20.6–43.3)	No limit
ASA	2.5	General anesthesia required
Urinary tract infection	13 (14%)	Adequate antibiotics
Renal units	Right: 40 Left: 50	Bilateral 5%
Number of stones	2.5 (1–6)	No exclusion criteria
Stone load (mm^2)	1621 (98–8512)	Maximal 3 cm
Presented	81 (90%)	Concept of presenting
b) Results		
Surgeons	3	All experienced with conventional FURS
Access sheath	90 (100%)	According to concept
Preparation of robot (min)	4.5 (3–8)	Short learning curve for staff
Docking time (min)	4 (2–29)	Temporary malfunction ($n=2$)
Visual contact to stone (min)	3 (–12)	Including inspection of colleting system
Stone migration	9 (10%)	–
Laser disintegration	83 (92%)	0.5 J/20 Hz
Stone clearance (mm^2/min)	25 (9–101)	Depending on stone composition
Use of NGage	81 (90%)	–
Radiation exposure ($cGy{*}cm^2$)	297	Mean fluoroscopic time 2 min 30 s
DJ-stent postop	90 (100%)	70% string fixed to catheter (1d)
Major complications Clavien IIIb	1 (1%)	Septicemia

Photothermal ablation through melting, carbonization, or chemical decomposition is confined to the area of light absorption. The speed at which heat leaves the site of light absorption depends on pulse duration: when pulse duration is much smaller than thermal diffusion time, heat conduction outside the stone-irradiate site is minimal [41]. A recent ex-vivo experiment analyzed laser-induced heat production in the ureter model revealing maximal temperatures of 37.4 C° with saline irrigation versus 49.5C° without. Even, if this model reflects incompletely real-life scenarios with heat convection due to intact vascular supply of ureter and collecting system, it demonstrates the importance of continuous saline irrigation during laser lithotripsy [50▪].

ROBOTIC FLEXIBLE URETEROSCOPY

Despite progress in design of ureterorenoscopes and accessories, surgeons have to work with suboptimal ergonomics, which may result in orthopedic complaints and be one of the reasons for imperfect performance [51,52].

Design of a robotic device could represent an alternative to improve ergonomics. Whereas trials to adapt the Hansen device developed for cardiology did not prove to be sufficient, successful clinical introduction of Avicenna Roboflex (ELMED, Ankara, Turkey) could be demonstrated [44▪▪,53]. Roboflex consists of surgeons' console, and a manipulator with exchangeable holders for three different digital ureteroscopes (Fig. 12). Surgeon controls two joysticks to manipulate the endoscope: right wheel enables deflection in finer degree than handpieces of standard instruments. Left joystick allows rotation and advancing/retracting. At console, surgeons fully control the inserted laser fiber and irrigation pump. Foot pedals of preferred laser lithotripters (i.e., Versa Pulse, Lumenis; Sphynx, Lisa Laser) are integrated in the console.

More than 250 patients have been treated worldwide. In Heilbronn, three surgeons performed 90 cases reproducing initial experiences and extending use of Roboflex for fragment removal (Table 3). Main advantages include accuracy of the system while providing a nonexhausting environment especially during long-lasting surgeries in technically demanding cases. Integration of Roboflex in daily routine could be managed without difficulties.

CONCLUSION

Recent technical developments of PCNL and FURS are based on improved video-technology, miniaturization, computation, and robotics. Endourology may now offer higher rates of primary success with minimal side-effects, which could weigh out slightly higher degree of invasiveness compared with ESWL.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:
■ of special interest
■■ of outstanding interest

1. Schnabel MJ, Brummeisl W, Burger M, *et al.* Shock wave lithotripsy in Germany: results of a nationwide survey. Urologe A 2015; 54:1277–1282.
2. Rassweiler J, Rassweiler MC, Frede T, Alken P. Extracorporeal shock wave lithotripsy: an opinion on its future. Indian J Urol 2014; 30:73–79.
3. Alken P, Hutschenreiter G, Günther R, Marberger M. Percutaneous stone manipulation. J Urol 1981; 125:463–466.
4. Rassweiler J, Gumpinger R, Miller K, *et al.* Multimodal treatment (Extracorporeal shock wave lithotripsy and endourology) of complicated renal stone disease. Eur Urol 1986; 12:294–304.
5. Michel MS, Trojan L, Rassweiler JJ. Complications in percutaneous nephrolithotomy. Eur Urol 2007; 51:899–906.
6. Su LM, Stoianovici D, Jarrett TW, *et al.* Robotic percutaneous access to the kidney: comparison with standard manual access. J Endourol 2002; 16:471–475.
7. Pollok R, Mozer P, Guzzo TJ, *et al.* Prospects in percutaneous ablative targeting: comparison of a computer-assisted navigation system and the AcuBot robotic system. J Endourol 2010; 24:1269–1272.
8. Meyer BC, Peter O, Nagel M, *et al.* Electromagnetic field-based navigation for percutaneous procedures on C-arm CT: experimental evaluation and clinical application. Eur Radiol 2008; 18:2855–2864.
9. Rassweiler JJ, Müller M, Fangerau M, *et al.* iPad-assisted percutaneous access to the kidney using marker-based navigation: initial clinical experience. Eur Urol 2011; 61:628–631.
10. Müller M, Rassweiler M-C, Klein J, *et al.* Mobile augmented reality for computer-assisted percutaneous nephrolithotomy. Int J Comput Assist Radiol Surg 2013; 8:663–675.
11. Huber J, Wegner I, Meinzer HP, *et al.* Navigated renal access using electromagnetic tracking: an initial experience. Surg Endosc 2011; 25:1307–1312.
12. Rodrigues PL, Vilaça JL, Oliveira C, *et al.* Collecting system percutaneous access using real-time tracking sensors: first pig model in vivo experience. J Urol 2013; 190:1932–1937.
13. 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; 31:1147–1151.
14. ■ Ritter M, Rassweiler MC, Michel MS. The Uro-Dyna-CT enables three-dimensional planned laser-guided complex punctures. Eur Urol 2015. doi: 10.1016/j.eururo.2015.07.005.
First clinical article on laser-assisted tracking for percutaneous renal access.
15. ■■ Rassweiler J, Rassweiler M-C, Müller M, *et al.* Surgical navigation in urology: European perspective. Curr Opin Urol 2014 2013; 24:81–97.
A study provides detailed overview about navigation techniques in urology.
16. Jackman SV, Docimo SG, Cadeddu JA, *et al.* The 'mini-perc' technique: a less invasive alternative to percutaneous nephrolithotomy. World J Urol 1998; 16:371–374.
17. Lahme S, Bichler KH, Strohmaier WL, Götz T. Minimally invasive PCNL in patients with renal pelvic and caliceal stones. Eur Urol 2001; 40:619–624.
18. Pugh J, Canales BK. New instrumentation in percutaneous nephrolithotomy. Indian J Urol 2010; 26:389–394.
19. ■■ Ferakis N, Stavropoulos M. Mini percutaneous nephrolithotomy of renal and upper ureteral stones: lessons learned from review of the literature. Urol Ann 2015; 7:141–148.
An excellent overview about recent developments in URS and PCNL.
20. ■ Nagele U, Nicklas A. Vacuum cleaner effect, purging effect, active and passive wash out: a new terminology in hydrodynamic stone retrieval is arising: dies it affect our endourologic routine? World J Urol 2015; 33: [Epub ahead of print].
An important summary of mechanism of hydrodynamic stone retrieval.
21. Knoll T, Jessen JP, Honeck P, Wendt-Nordahl G. Flexible ureterorenoscopy versus miniaturized PCNL for solitary renal calculi of 10-30 mm size. World J Urol 2011; 29:755–759.
22. Sabnis RB, Ganesamoni R, Sarpal R. Miniperc: what is current status? Curr Opin Urol 2012; 22:129–133.
23. ■■ Nicklas AP, Schilling D, Bader MJ, *et al.* Training and Research in Urological Surgery and Technlogy (T.R.U.S.T.)-Group. The vacuum cleaner effect in minimally invasive percutaneous nephrolitholapaxy. World J Urol 2015; 33: [Epub ahead of print].
Basic study to understand hydrodynamics of PCNL.
24. Nagele U, Walcher U, Bader M, *et al.* Flow matters 2: how to improve irrigation flow in small-calibre percutaneous procedures the purging effect. World J Urol 2015; 33: [Epub ahead of print].
25. Mishra S, Sharma R, Garq C, *et al.* Prospective comparative study of miniperc and standard PNL for treatment of 1-2 cm size renal stone. BJU Int 2011; 108:896–899.
26. Desai J, Solanki R. Ultra-mini percutaneous nephrolithotomy (UMP): one more armamentarium. BJU Int 2013; 112:1046–1049.
27. Zeng G, Wan S, Zhao Z, *et al.* Super-mini percutaneous nephrolithotomy (SMP): a new concept in technique and instrumentation. BJU Int 2015. [Epub ahead of print]
28. Desai M, Mishra S. 'Microperc' micro percutaneous nephrolithotomy: evidence to practice. Curr Opin Urol 2012; 22:134–138.
29. ■ Schilling D, Hüsch T, Bader M, *et al.* Training and Research in Urological Surgery and Technology (T.R.U.S.T.)-Group. Nomenclature in PCNL or the tower of Babel: a proposal for a uniform terminology. World J Urol 2015; 33: [Epub ahead of print].
An important proposal of classification for miniaturized PCNL.
30. Bellman GC, Davidoff R, Candela J, *et al.* Tubeless percutaneous renal surgery. J Urol 1997; 157:1578–1582.
31. Preminger GM, Tiselius HG, Assimos DG, *et al.* American Urological Association Education and Research, Inc; European Association of Urology. 2007 Guideline for the management of ureteral calculi. Eur Urol 2007; 52:1610–1631.
32. Hüsch T, Reiter M, Mager R, *et al.* The management of the access tract after percutaneous nephrolithotomy. World J Uroi 2015; 33: [Epub ahead of print].
33. Okhunov Z, del Junco M, Yoon R, *et al.* In vitro evaluation of LithAssist: a novel combined holmium laser and suction device. J Endourol 2014; 28:980–984.
34. Breda A, Ogunyemi O, Leppert JT, Schulam PG. Flexible ureteroscopy and laser lithotripsy for multiple unilateral intra-renal stones. Eur Urol 2009; 55:1190–1196.
35. ■■ Bach T, Muschter R, Herrman TRW, *et al.* Technical solutiona to improve the management of noninvasive transitional cell carcinoma: summary of European Association of Urology Section of Uro-Technology (ESUT) and Section for Uro-Oncology (ESOU) expert meeting and current and future perspectives. BJU Int 2015; 115:14–23.
Landmark study on new imaging techniques and management of noninvasive bladder cancer.
36. Bach T, Netsch C, Hermann TR, Gross AJ. Objective Assessment of working tool impact on irrigation flow andvisibility in flexible ureterorenoscopes. J Endourol 2011; 25:1125–1129.
37. ■ Traxer O, Wendt-Bordhal G, Sodha H, *et al.* Differences in renal stone treatment and outcomes for patients treated either with or without the support of a ureteral access sheath: The Clinical Research Office oft he Endourological Society Ureteroscopy Global Study. World J Urol 2015; 33: [Epub ahead of print].
Results of largest registry worldwide.
38. Somani BK, Aboumarzouk O, Srivastava A, Traxer O. Flexible ureteroscopy: tips and tricks. Urol Ann 2013; 5:1–6.
39. ■ Kronenberg P, Traxer O. Update on Lasers in Urology. Current assessment on holmium: yttrium-aluminum-garnet (Ho: YAG) laser lithotripter settings and laser fibers. World J Urol 2015; 33:1030–1035.
Excellent overview over current knowledge on laser settings and fibers.
40. Rassweiler J, Irion U, Strauss R, *et al.* Technical considerations using a pulsed Neodym-YAG laser for endoscopic shock wave lithotripsy. Eur Urol 1989; 16:374–377.
41. Zhomg P, Tong HL, Cocks FH, *et al.* Transient cavitation and acoustic emission produced by different lasers. J Endourol 1998; 12:371–378.
42. Spore SS, Teichman JMH, Corbin NS, *et al.* Holmium: YAG lithotripsy: optimal power settings. J Endourol 1999; 13:559–566.
43. Kronenberg P, Traxer O. In vitro fragmentation efficiency of holmium: yttrium-aluminium-garnet (YAG) laser lithotripsy – a comprehensive study encompassing different frequencies, pulse energies, total power levels and laser fibre diameters. BJU Int 2014; 114:262–267.
44. ■■ Saglam R, Muslumanoglu AY, Tokatlı Z, *et al.* A new robot for flexible ureteroscopy: development and early clinical results (IDEAL Stage 1-2b). Eur Urol 2014; 66:1092–1100.
First clinical study on robotic FURS with Avicena Roboflex.
45. Chawla SN, Chang MF, Chang A, *et al.* Effectiveness of high-frequency Holmium: YAG laser stone fragmentation: the 'popcorn effect'. J Endourol 2008; 22:645–649.
46. Rassweiler J, Westhauser A, Bub P, Eisenberger F. Second-generation lithotripters: a comparative study. J Endourology 1988; 2:193–203.
47. Duryea AP, Roberts WW, Cain CA, Hall TL. Controlled cavitation to augment SWL stone comminution: mechanistic insights in-vitro. IEEE Trans Ultrason Ferroelectr Freq Control 2013; 60:301–309.
48. Bader MJ, Pongratz T, Khoder W, *et al.* Impact of pulse duration on Ho: YAG laser lithotripsy: fragmentation and dusting performance. World J Urol 2015; 33:471–477.
49. ■ Kronenberg P, Traxer O. Are we doing it wrong? Influence of stripping and cleaving methods of laser fibres on laser lithotripsy performance. J Urol 2015; 193:1030–1035.
Important study how to use laser fibers.
50. ■ Molina WR, Silva IN, da Silva RD, *et al.* Influence of saline on temperature profile of laser lithotripsy activation. J Endourol 2015; 29:235–239.
First study dealing with the problem of heat during Holmium:Yttrium-Aluminium-Garnet-laser lithotripsy.
51. Elkoushy MA, Andonian S. Prevalence of orthopedic complaints among endourologists are common and their compliance with radiation safety measures very important. Endourol 2011; 25:1609–1613.
52. Healy KA, Pak RW, Cleary RC, *et al.* Hand and wrist problems among endourologists are very common. Endourol 2011; 25:1905–1920.
53. Desai MM, Grover R, Aron M, *et al.* Robotic flexible ureteroscopy for renal calculi: initial clinical experience. J Urol 2011; 186:563–568.