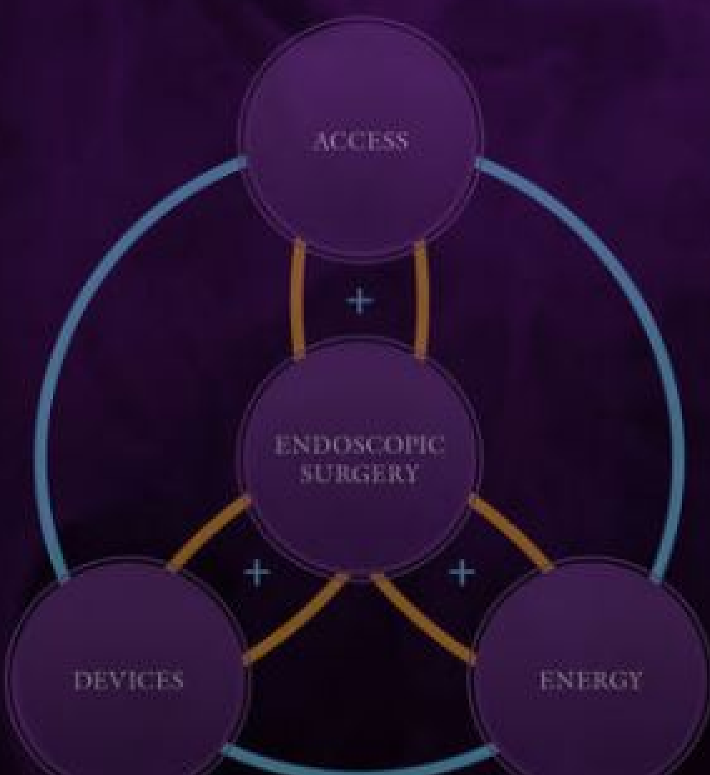
TWO-VOLUME SET

SMITH'S TEXTBOOK OF ENDOUROLOGY

FOURTH EDITION

EDITED BY
ARTHUR SMITH
GLENN PREMINGER
LOUIS KAVOUSSI
GOPAL BADLANI



with website

WILEY Blackwell

57

Retrograde Intrarenal Surgery in the Future: Robotics

Anup Patel

Consultant Urological Surgeon, London, UK

Introduction

As the world enters the fourth industrial revolution, there will be rapid evolution in the areas of artificial intelligence (AI), robotics, three-dimensional (3D) printing, nanotechnology, genetics, and biotechnology. "Robots" have been part of human society since before Leonardo Da Vinci described gears, wheels, and pulleys to animate a robotic knight for a Milan pageant in the 1490s. *Robot*, a derivation of the Czech word "robota" from a 1920 play entitled *R.U.R.* (*Rossumovi Univerzalini Roboti*) by Czech author Karel Capek, meant forced labor or serf. Capek described fictional human-like machines that continuously performed repetitive hard, dull, or dangerous complicated tasks for their human counterparts without feeling. The machines eventually became "resentful," rebelled, and killed all the humans. Consequently, over time, the word "robot" has encompassed several meanings including that of a brutal human being who has become insensitive or machine-like because of overwork and mistreatment. In 1939, after meeting Ernest and Otto Binder at the Queens Science Fiction Society, who had published a story entitled *I, Robot* about a sympathetic misunderstood robot called Adam Link (who was motivated by love and honor), and following a conversation a year later with John W. Campbell, Isaac Asimov introduced his Three Laws of Robotics in a short story called "Runaround."

1) A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2) A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.
3) A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws.

A fourth law was later added:

4) A robot may not harm humanity, or, by inaction, allow humanity to come to harm.

Since then, robots have been remade in mankind's image, and popularized by the televisual industry. Before Azimov, Edgar Allen Poe (1839) related the story of a wounded soldier whose body was rebuilt with synthetic parts. During the early part of the space race (1960) this was termed a cybernetic organism, for it was envisaged that blending technology with astronauts' bodies could help endurance and survival in space. This led to a plethora of medical technologies such as pacemakers, insulin pumps, cochlear implants, prosthetics, and exo-suits, all of which are already integrated into human society.

In today's world, the real issues regarding robots' future roles center over debate as to whether they will primarily augment or replace current human functions. Autonomous robotic technology has increasingly replaced traditional tedious repetitive industrial human manufacturing roles, performing dull, dirty, and dangerous tasks, leaving their human counterparts in the shade for both accuracy and efficiency. Simultaneously, programmable and master/slave-controlled drone technology, automated driverless vehicles (cars and airplanes), and crop spraying and seed dispersal farming drones have all begun to impact different aspects of daily human life, while also replacing humans in situations of inherent task-associated danger. Where sustained precision, reliability, reduced costs, and greater productivity are desired, advanced sensor robotic technology can

Smith's Textbook of Endourology, Fourth Edition. Edited by Arthur D. Smith, Glenn M. Preminger, Louis R. Kavoussi, and Gopal H. Badlani.

Companion website: www.wiley.com/go/smith/textbookofendourology

easily augment or supplant human performance without fatigue. More human functions are or will be threatened in the coming years, and some have even predicted that the ultimate supremacy of robotic over human development will be reached in only two more decades. It is a potential revolution akin to the Internet, where robots can fulfill diverse roles in society as human substitutes, companions, and partners (co-bots).

For medical applications, a key issue is whether robotic machines are better, or simply enhance human performance by lacking or reducing fatigability, allowing greater precision and efficiency over longer durations. This is particularly true for master/slave devices where expensive development costs can be offset by time saved, greater task performance precision, and increased productivity, and perhaps also consistency, particularly in repetitive or endurance-based tasks. Ideally, a master/slave human–robot partnership should enhance the capability of each individual component part provided the master can maintain concentration throughout the task. In interventional urology, robotics has already made great inroads through the use of devices that are master-independent, such as the PUMA560 [1] (1988; arm with six degrees of freedom used for brain biopsy and later for transurethral resection of prostate) and, more recently, the Cyberknife for precision radiotherapy. Zeus and Aesop (US Food and Drug Administration [FDA] approved in 1990; Computer Motion, Santa Barbara, CA, USA), were bought and quashed by Intuitive Surgical (Sunnyvale, CA, USA) in favor of their Da Vinci™, a next-generation master/slave console-controlled robotic device with endo-wrist technology (FDA approved in 2000) [2, 3]. It and the Sensei-Hansen device (Hansen Medical, Mountain View, CA, USA) [4, 5] were their urological successors, incorporating console-based 3D optical visualization with magnification, motion control and scaling, tremor reduction, and a greater range of movement and ergonomics compared to traditional instruments. Although it is beyond the scope of this chapter to examine cost-benefits, this aspect of all new technologies will be amplified in an era of economic austerity coupled to higher healthcare demands from chronic illness, fueled by obesity and ageing pandemics, and falling birth rates in the world's developed nations.

Rupel and Brown's endourological legacy of cystoscopic nephroscopy for renal stones at open surgery in 1941 [6] has been the evolution of a wide range of extracorporeal, ureteroscopic, percutaneous, and laparoscopic procedures, all embraced by urologists worldwide. The dominant large/branched renal stone treatment remains percutaneous nephrolithotomy (PCNL). Nevertheless, after two decades of evolution, classical retrograde intrarenal surgery (cRIRS) is now the most dominant endourological stone treatment modality overall. Expertise and allied technological growth has projected cRIRS to the mainstream of complex endourological stone and soft tissue treatment in the upper urinary tract. For the first time, cRIRS rightly challenges the dominant alternative of PCNL treatment of larger intrarenal calculi [7–12]. However, cRIRS for large stones remains a technically challenging procedure requiring specific expert endo-skill sets, real-time problem solving capabilities [13–15], and both physical and mental endurance. Even when ureteral access sheaths (UAS) are used (almost mandatory in this setting), and the stone(s) can be accessed and completely laser-fragmented, the single-sitting stone-free rate is limited by the operator's stamina during long dusting and "pop-corning" procedures, and the size and number of stone fragments that can safely be removed down the ureter in a safe, timely manner (in turn dependent on stone composition and hardness, and collecting system anatomy). Additional limiting factors are current flexible ureterorenoscope (FUR) design, a moving target (renal respiratory excursion) during fragmentation, and awkward calyceal anatomy, particularly if several such cases are scheduled per day. This has resulted in ≥50% secondary procedure rates to render patients stone-free. Furthermore, the surgeon depends on assistants for key task performance, to activate lasers (standby-ready and energy-rate settings adjustments), deploy nitinol baskets and capture fragments, maintain and enhance irrigant flow, aspirate, and to draw/inject contrast, while manipulating and targeting the ureterorenoscope tip. All operating room staff are exposed to radiation over a longer period (range of 1.7–56 μSv [16–18]). Meanwhile, less invasive evolutionary PCNL techniques (mini, ultra-mini, super-mini, and micro-PCNL [19–24]) have also evolved to challenge cRIRS, to gain parity or ascendancy in the current larger renal stone treatment paradigm, particularly in Asia, so further technological and technique evolution is mandated.

During the last two decades, significant changes in both semirigid and FUR design, specifically tip and shaft size reduction along with configuration changes, have facilitated easier natural orifice access into the upper urinary tract for the majority of users (albeit at the cost of increased fragility and repair costs). Greater direction and range of tip deflection (both single and dual active flexion/extension motion range) has made navigation through the intrarenal collecting system easier, allowing more urologists to reach and inspect >95% of the entire collecting system (the most challenging part being the lower antero/medial calyx, especially in a dilated pelvicalyceal system which limits use of both active and secondary passive deflection).

In 2012, ELMED (Ankara, Turkey) started developing a procedure-specific robot-assisted RIRS (RA-RIRS) device [25]. The IDEAL (idea, development, evaluation, assessment, long-term study) framework for surgical innovation stages was embraced from prototype to the commercially available Avicenna Roboflex (IDEAL stage 1), and early clinical experience with treatments performed by different experienced endourologists (IDEAL stages 2–4) was reported as follows.

Device development

The basic Avicenna Roboflex design from prototype (Figure 57.1a) to successive versions (Figure 57.1b–d) consisted of a master control console (MCC) seating the surgeon and a manipulator arm (MA), which can now be coupled to any standard commercially available FUR using a custom-made model-specific adapter. During the early developmental phase, incremental improvements were made to the size and design of the MCC, the joysticks to control advancement, rotation, and tip deflection, and to develop a system to remotely advance-retract the laser fiber.

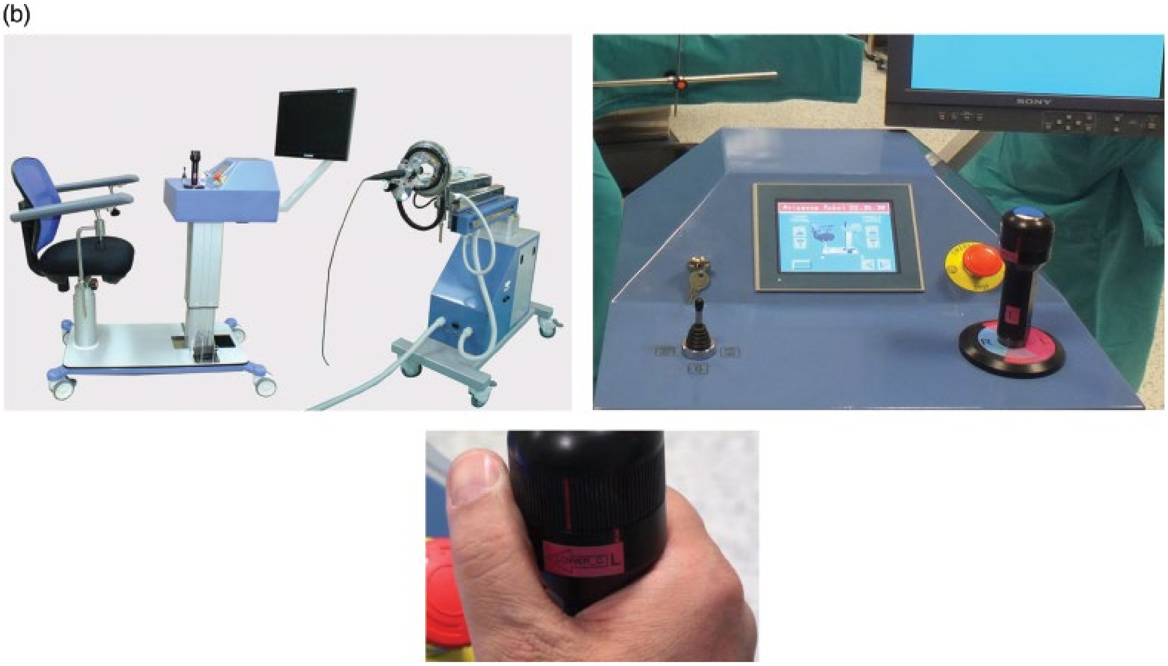
Master control console design features

The current Avicenna Roboflex (version 5) MCC (Figure 57.2a) is connected to the MA unit, and its monitor is connected as a slave to the operating room stack monitor. It has key-control on-switch, with separate red push-button emergency stop (Figure 57.2b). The MCC reclining seat has adjustable height, head, and armrests. Six users can store individual seat positions and all preferred custom deflection-scaling settings in the system memory (Figure 57.3). The comfortably seated surgeon activates wheel locks, selects endoscope type, brightness, time, background screen color (one of six options), rotation precision and direction, deflection precision, and horizontal plane movement speed via the set-up menu. Moreover, they can also select low- (0.5×) or high-precision (1.5×) modes, timer stopwatch start or reset options, and define target kidney side (right or left) on the touch-screen panel (also displayed on the center right of the monitor screen). The MCC touch screen also allows control of laser fiber actuator, irrigation flow rate, short bursts of flush, and abdominal compression belt inflation to reduce renal respiratory movement (Figure 57.4). Below this on the monitor screen is the endoscope deflection and rotation icon, and above it are laser fiber and irrigation flow rate indication bars (Figure 57.5). The rotation display circle containing the endoscopic view is in the center. The surgeon controls two joysticks (with adjustable padded wrist support) to manipulate the FUR, which is mounted on the MA component. The right-hand vertical joystick bulb's "magic wheel" controls fine tip deflection akin to the handpiece of any standard FUR (Figure 57.6a), but with additional tenfold motion scaling. The deflection direction (upwards, downwards) can be programmed for logical deflection (down = tip down and up = tip up) or counterintuitive deflection (down = tip up and vice versa). The new horizontal left joystick (Figure 57.6b) allows clockwise and counterclockwise MA rotation, as well as advancement and retraction of the endoscope shaft with millimeter per second adjustment, using +/− buttons. The rotation speed, scale (2, 1, 0.5×) and MA rotation direction (clockwise or counterclockwise), and advancement can be regulated by console touch-screen control. Warning display box alerts inform the user about rotating the MA to the mounting position (90° clockwise), continuing from a particular position, or returning to the neutral position.

Figure 57.1 (a) Avicenna Roboflex version 1 prototype for RA-RIRS: simple circular holder for FURS control and laser fiber movement, controlled from console with two small four-way joysticks (left for forward/backward and laser fiber in/out, right for rotation clockwise/counterclock wise, and deflection up/down). The joysticks were later modified with bigger, thicker handles. (b) Similar manipulator arm with longer horizontal movement (forward/backward movement) for easier basket application, and smaller control console with height adjustable seat. Control of the left joystick movements were unchanged, but right joystick had a thick, rotatable handle to control FUR rotation and there was another individually rotatable disk incorporated into the top of the joystick handle to control up/down deflection. (c) Version 3: new manipulator arm design (with high-precision robotic components) with open-type endoscope holder and new master control console (MCC). Rotation movements over 440° were designed for smooth precision following hand movement. Special endoscope holder was designed for easy docking with deflection control unit. A force-torque deflection mechanism sensing system was developed to protect the device against high-deflection torsion. Horizontal movement (forward/backward) was set to a speed of 22 mm/second (adjustable from 0.5 to 22 mm/second). The MCC was designed with two joysticks to control rotation and forward/backward movement (left joystick), and deflection movement on the right joystick. Laser fiber movement and vertical movement (according to patient tabletop position) were controlled from the touch screen. Later, a central precision control cylinder was added to the center of the MCC for fine tip deflection control as a modification of that version. (d) Version 4 incorporating a new interchangeable endoscope holder system to accommodate all FUR brands/models. The right joystick controlled rotation and two-stage speed control for forward/backward movements and incorporated a thumb wheel ("magic wheel") for tip deflection. Precision or scale of all rotation and tip deflection movements were selectable from the MCC touch screen. A new MCC foot-pedal unit was incorporated to control any laser or fluoroscopy foot pedals. Additional visual guidance was provided on the video monitor screen to indicate the spatial position of the FUR (such as horizontal distance, rotation angle, and deflection angle).

(a)

(b)



(c)

(d)

Figure 57.1 (Continued)

(a)

(b)

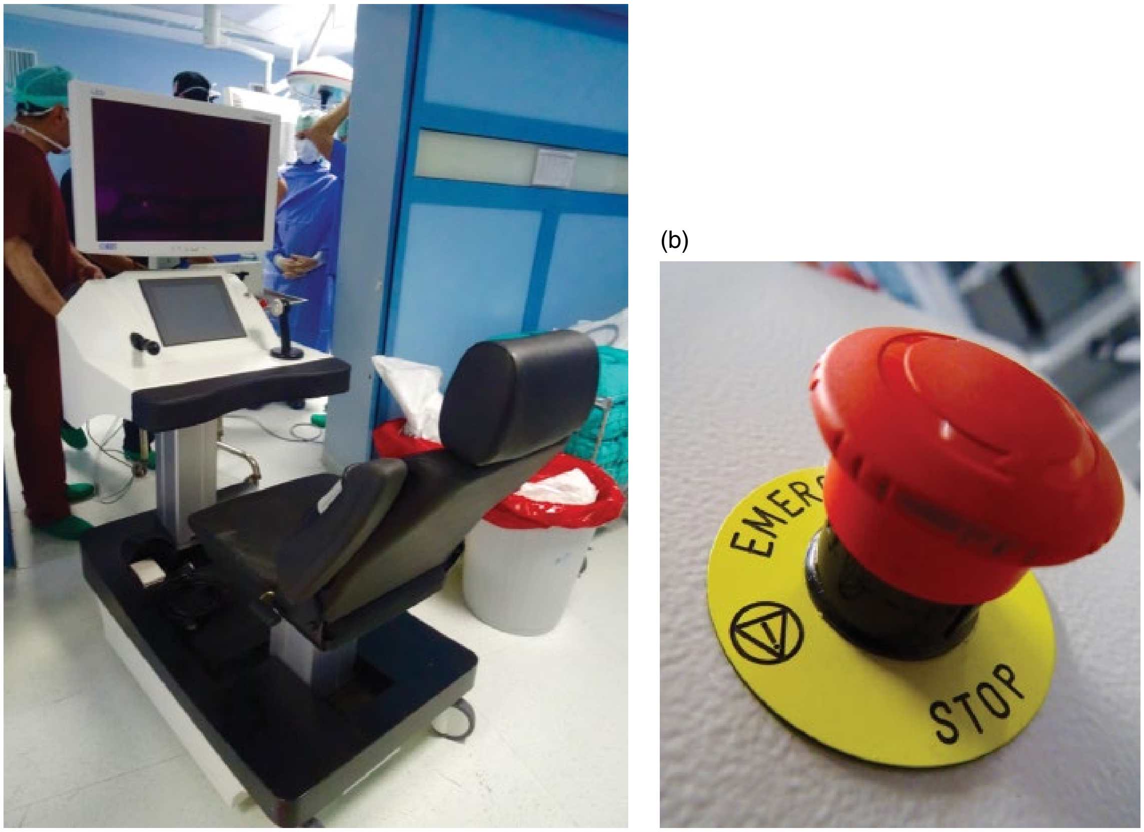


Figure 57.2 (a) Version 5 MCC unit with key control start, and improved adjustable seat design, headrest, and wrist support bar as an ergonomically sound comfortable surgical workstation. Horizontal left joystick for horizontal and rotational movement control, and right vertical joystick with magic wheel to control fine tip deflection (all with adjustable precision from MCC touch screen). (b) Red emergency stop button.

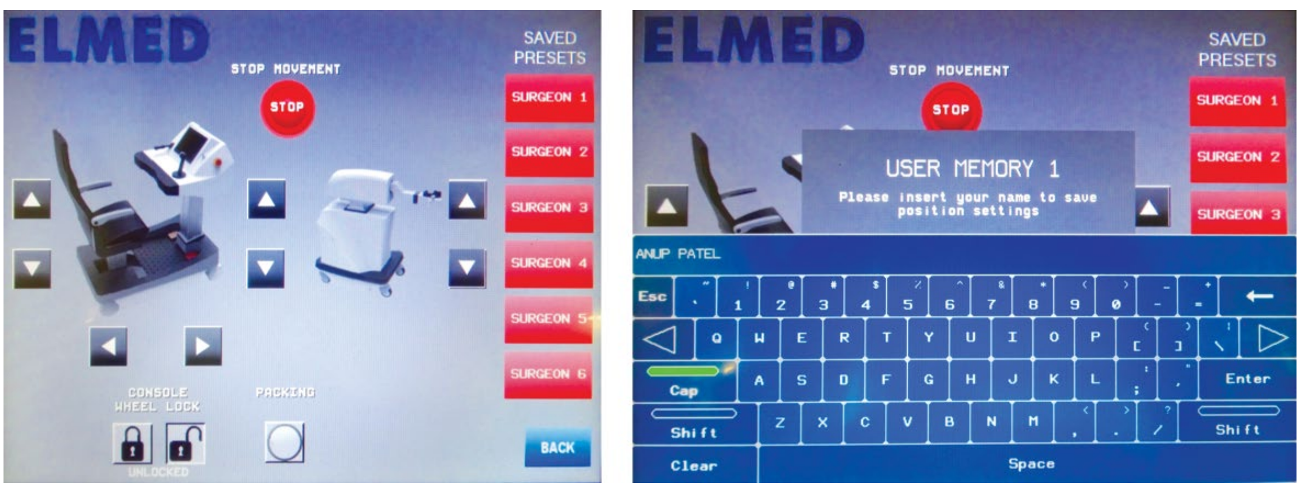


Figure 57.3 System memory for six users.

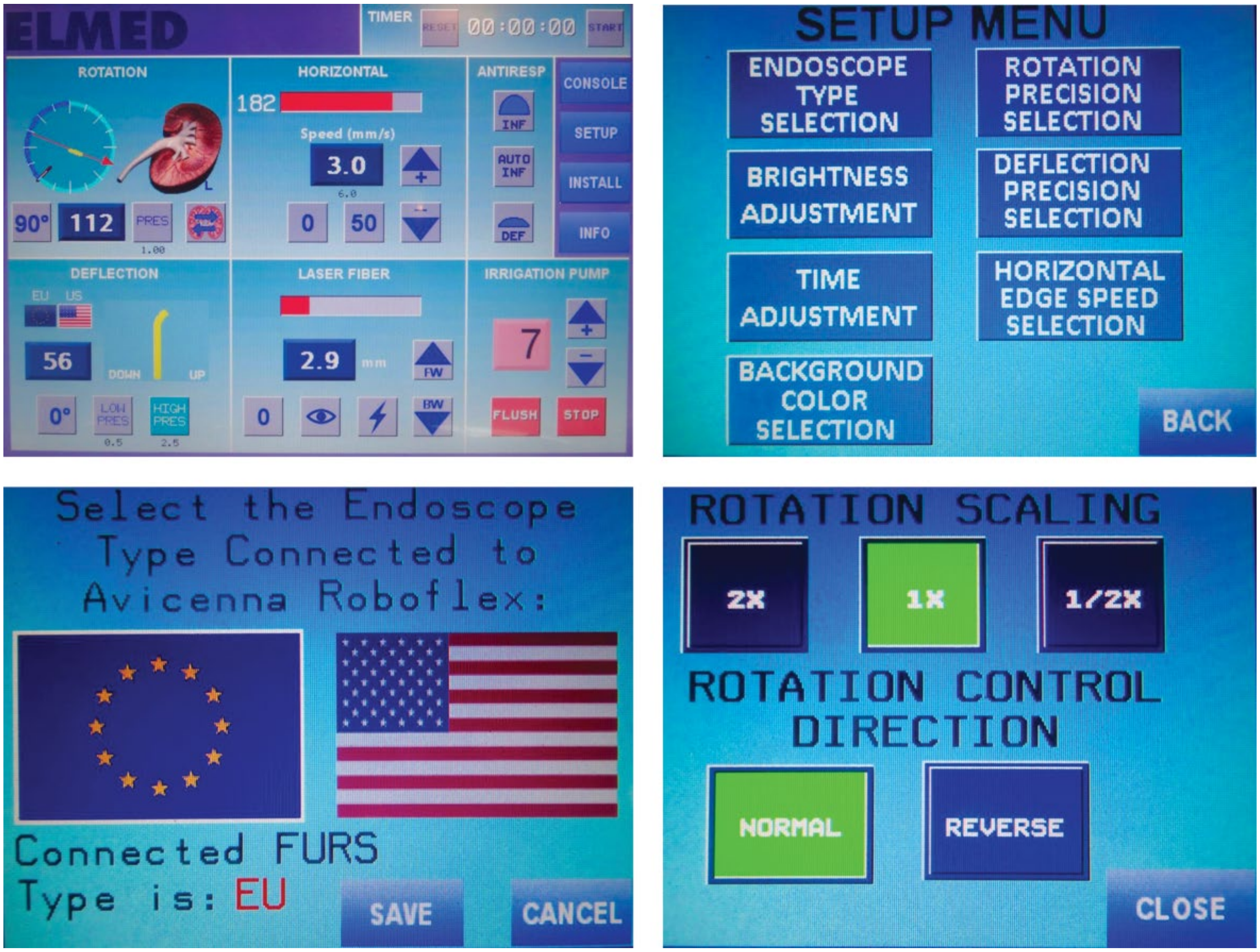


Figure 57.4 The MCC touch screen with various functions in the set-up menu: adaptation to FUR mode (i.e. American or non-American), change of rotation, deflection precision, horizontal advancement/retraction speed, laser fiber advancement and retraction, irrigation flow rate adjustment, compression belt inflation-deflation, and degree of rotation, deflection, and horizontal insertion display, along with timer and stop watch.

The assistant introduces the laser fiber at the start with the endoscope tip in a "0" straight position, with the tip cladding just visible endoscopically, and the touch-screen "eye button" in the laser fiber box is pressed. The zero button is then activated to level the fiber tip with the work-channel exit point. The endoscope can now be safely maneuvered to the stone before advancing the fiber tip 1.8 mm for safe firing. The MCC floor-mounted red right foot pedal controls laser firing, while the white left pedal controls the fluoroscopy (Figure 57.7a), both aided by compressed air cabling to a foot-pedal coupler unit (Figure 57.7b). The laser fiber foot pedal is automatically disabled when the fiber tip is within 1.6 mm of the endoscope tip (the red warning bar is a useful safety feature).

Manipulator arm design

The MA consists of computer-controlled motor systems, a robotic arm, which holds and moves the endoscope, and the lower stabilizing arm to which vertical supports are attached in two places. The arm height can be adjusted according to the patient's anatomy. The endoscope hand piece with appropriately placed deflection lever is fixed into the arm's customized coupler housing and secured by double clip holders after draping (Figure 57.8). The distal vertical stabilizer is fixed to the preplaced UAS hub, while the proximal one stabilizes the straight endoscope shaft approximately 5 cm further back (Figure 57.9a). A UAS is virtually mandatory for Avicenna Roboflex procedures, due to lack of haptic

Figure 57.4 (Continued)

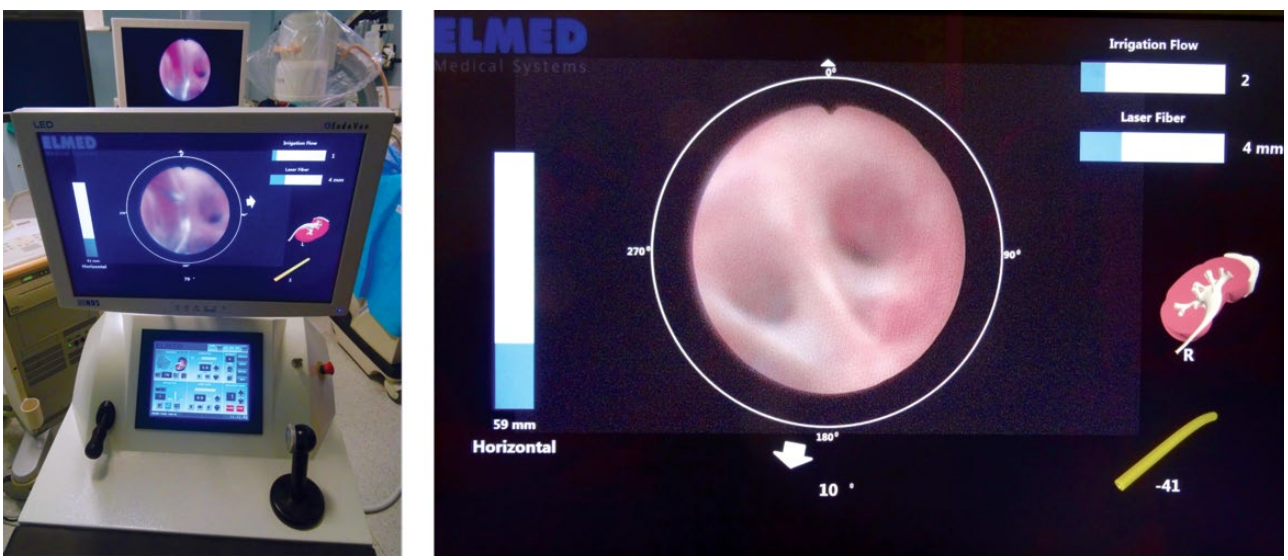


Figure 57.5 MMCC with slave monitor screen for endoscopic image within central rotation indicator circle, progress bars for irrigation flow rate and laser fiber extrusion distance from tip (mm) on right upper, side of kidney right central, FUR tip deflection indicator right lower, and insertion rate progress bar left of center.

Figure 57.6 (a) Magic wheel atop bulb of right-hand MCC control joystick for fine scaled up-and-down endoscope tip deflection. (b) Left-hand horizontal control joystick of MCC for clockwise and counterclockwise rotation, and in-and-out endoscope movement.

feedback, reducing risk of inadvertent ureteral injury. The custom-made coupler accepts any FUR, although initial development was made using a digital instrument (Flex-XC; Karl Storz, Tuttlingen, Germany). The MA can be rotated bidirectionally by 210° allowing overlap for a total 440° compared to 120° for humans. Miniaturized hand-piece adaptor motors allow endoscope steering lever movement for deflection and enable motion scaling of the cable-based endoscope tip movement mechanism. Due to FUR design and cabling inertia, a short lag period between robot control and endoscope tip reaction exists. This is vital for the user to understand and remember, for there is a tendency to continue MCC deflection if no immediate visible screen reaction is seen, leading to delayed deflection overshoot. The same lag occurs for the same reason when switching deflection direction. Normally, a 10° manual lever deflection moves the tip 60°. With Avicenna Roboflex, FUR tip control precision is eightfold greater than manual operation. The thumb-wheel scaling precision, which can be low or high, or on a scale of 1–10 as set on the MCC, allows 10° of thumb movement to result in 3–30° of tip deflection. The applied forces were limited to 1 N/mm^2 for safety to minimize the risk of collecting system and endoscope injury.

Moreover, the coupling hand-piece adapter accepts placement of a micromotor-driven actuator system, which is connected to the instrument's working-channel for precise laser fiber advancement (Figure 57.9b).

(a)

(b)

Figure 57.7 (a) MCC floor-mounted red right foot pedal (for laser firing control) and white left pedal (for fluoroscopy control). (b) Compressed air cable activated foot-pedal coupler unit.

Experimental evaluation

For all MCC steering, and movement reliability functions, the Avicenna Roboflex was tested in a validated flexible ureterorenoscopy *in vitro* training model (Minnesota University Kidney Model [25]) containing artificial stones. This enabled safe prototype(s) simulations to evaluate key parameters and all device functions. It was also used for hands-on training of all participating surgeons.

In vitro studies

Avicenna Roboflex showed safe, stable maneuverability, with easy translation of MCC functions when in both bench training models and pig ureters. Prototype ergonomics were already good, but incremental improvements to wrist movements, and fine-tuning of deflection were made.

Surgical technique

With the patient under general anesthesia, supine in lithotomy, intravenous diuretic (lasix) and antibiotic prophylaxis are given, and manual cystoscopy, retrograde pyelography, and placement of a safety guidewire can be performed. The ureteral orifice is accessed with a semirigid ureteroscope, inspecting the ureteral lumen up to/beyond the ureteropelvic junction, thereby achieving maximal optical ureteral orifice and ureteral dilation, leaving behind a working wire as needed. A suitable size (10–12/12–14 Fr) and length (35–46 cm) UAS is then advanced into the upper ureter under fluoroscopic control as needed, confirming ureteral integrity postplacement with further pyelography via the access sheath obturator.

Figure 57.8 The MA custom endoscope coupler and motorized actuator housing, with FUR hand piece fixed in the manipulator coupler and stabilized by double clip holder after draping.

(a) (b)

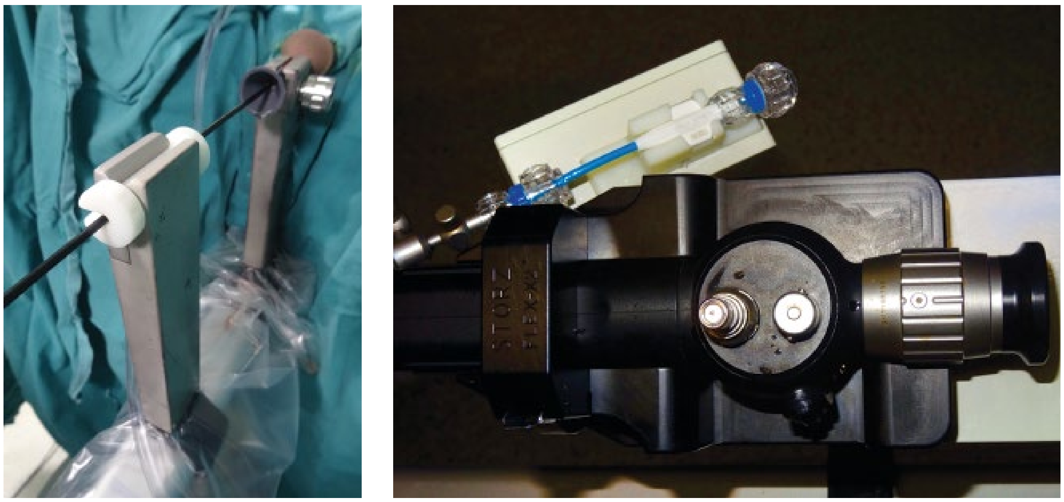


Figure 57.9 (a) The proximal stabilizer supports the straight endoscope shaft, while the distal stabilizer fixes the UAS shaft in the same plane. (b) The laser fiber (and irrigation tube) is attached to the endoscope by a motorized actuator for fine laser fiber movements.

Next, the FUR is inserted into the UAS lumen and its hand piece is fixed in the sterile plastic-draped robotic-arm coupling adaptor, where it is securely locked with securing clips. Thereafter, checks are made for a stable, secured, straight FUR shaft, before console steering can begin. Using the MCC touch screen and control levers, the target stone(s) is endoscopically visualized and recorded with fluoroscopic snapshot (master console floor left foot pedal). If the laser fiber was not inserted at the start, the endoscope is placed in a neutral straight retracted position with the console zero button to guarantee safe laser fiber insertion without risking work channel damage. The MCC provides a memory function to guide the scope back to its previous position near the stone surface after laser fiber insertion. The inserted laser fiber tip with cladding should be just visible near the endoscope tip and the eye button on the master control laser fiber box is activated for memory entry. Only then can the fiber be retracted to a position level with the scope tip (zero button) and advanced from there by the console touch screen controls using the actuator device fitted to the endoscope work channel. The fiber cannot be retracted inadvertently into the scopes working channel and energy activated, where it might damage the instrument. Once the fiber is advanced (as shown by bicolored bar in MCC laser fiber panel) with precision to the optimal distance from the stone surface, laser-induced lithotripsy can be initiated, ideally "dusting" the stone surface with meandering rotation and small up-and-down deflection movements of the laser fiber tip in the millimeter range using the left hand rotation control lever and/or the right hand pin-wheel control, or by fragmentation (various techniques). Any commercially available holmium:YAG laser unit can be used, but one that allows higher-frequency application at low energy is recommended for optimal dusting. Smaller fiber sizes allow sufficient scope tip deflection with lowest risk of fiber fracture in the work channel at maximum energy and frequency. Once fragmentation has started, higher energy frequency gives a "popcorn effect" for fragment pulverization when dusting is not possible. Sometimes, with fiber tip in the calyx lumen center, this can even be done "hands-free" if time-consuming (see Video 57.1). Fiber tip erosion must be monitored, as it reduces energy transfer over time, and judicious appropriate cleaving with fiber re-introduction is undertaken as required. To introduce nitinol baskets for fragment retrieval at the end, the laser actuator has to be driven back to its preset zero position with the endoscope tip straight, and the fiber exchanged for the basket, once the laser console is on standby (assistant). This might be time-consuming especially if there are multiple fragments, and hence ablation by stone dusting is preferred until a suitably sized fragment is retrieved at the end for stone analysis. The need for JJ stent placement at the end of the procedure is not mandated, but left to the operator's discretion.

Published clinical experience

Patients and outcomes

In the first peer-reviewed study, Ankara Medical School ethics commission approval was secured, and 81 patients were treated (IDEAL stage 2) (Table 57.1). Inclusion criteria were aged >6 year, single or multiple stones with a 30 mm total diameter ceiling, absent active urinary tract infection, and no previous ureteral surgery. All patients or minors' parents were informed about Avicenna

Table 57.1 Baseline RA-RIRS demographic and outcomes data ($n = 81$).

Criteria	Value	Range	SD	Comment
Age (years)	42[a]	6–68	25.4	According to inclusion criteria
Male/female	56/25	–	–	–
Left/right	35/46	–	–	–
Single/multiple calculi	29/52	–	–	–
Upper calyx	62	–	–	–
Middle calyx	23	–	–	–
Lower calyx	62	–	–	–
Renal pelvis	26	–	–	–
Stone diameter (mm)	13[a]	5–30	5.3	Multiple calculi: sum of lengths
Stone volume (mm^3)	1296[a]	432–3100	544.3	Calculated based on preoperative computed tomography
Treatment time (minutes)	74[a]	40–182	31.8	Inclusive of UAS and double-J stent placement
Robot docking time (seconds)	59.6[a]	35–124	45	46 seconds after 42 cases
Stone visualization time (minutes)	3.7[a]	2–8	1.4	Including complete inspection of collecting system
Fragmentation time (minutes)	46[a]	18–115	21.7	Depending on stone size/hardness
Fragmentation speed, (mm^3/minute)	29.1[a]	18–46	6.1	Increasing to 32.7 mm^3/min after 42 cases
Console time (minutes)	53[a]	23–135	23.2	Depending on stone size and learning curve
Complications	1	–	–	Endoscope failure (case 42), cRIRS not possible; double-J stent placement
Ergonomic scores				
cRIRS	31.3[a]	16–40	7.8	Based on last 10 cases performed by each surgeon at own institution
RA-RIRS	5.6[a]	3–10	2.4	Based on immediate subjective evaluation
Re-treatment	2	–	–	cRIRS
Robotic failure	None	–	–	–
3-month stone-free rate	65 (80%)	–	–	16 patients (20%) with clinically insignificant residual fragments ≤3 mm

UAS in 72 patients; nine patients with tight ureters (six children and three females) had optical rigid ureteroscopic dilation, placement of safety guidewire, and FUR without UAS. Seven experienced surgeons (5–16 years' individual cRIRS experience) with all MCC Avicenna Roboflex functions learned in the *in vitro* training model.
SD, standard deviation.
[a] Mean value.
Source: [26]. Reproduced with permission of Elsevier.

Roboflex use and provided informed consent. Primary end points included RA-RIRS safety and reproducibility based on successful fragmentation data, second sessions, auxiliary measures, complications (Clavien-Dindo classification), and any FUR-related/robot malfunction. Secondary end points were robot docking time, stone location time, fragmentation time, and speed (cubic millimeters per minute) based on computed tomography (CT) stone volume evaluation [27–29], console, and treatment time. Numerical data were expressed as mean with standard deviation (SD) including range; categorical data were expressed as numbers. SPSS v.15 (IBM Corp, Armonk, NY, USA) was used for data analysis. Categorical variables were analyzed using the $\chi 2$ test (or Fisher exact test). The Mann–Whitney U test was used for numeric variables. P values <0.05 were considered statistically significant.

79 patients (97%) had complete stone disintegration. One patient with a large lower calyceal stone (2.5 cm) had intraoperative digital FUR failure (case 42; broken video system); cRIRS conversion did not allow procedure completion due to complicated access plus stone burden, and interval cRIRS was needed 5 days later. Another patient required secondary cRIRS for significant residual fragments. All patients had DJ stents, with removal after a median 7 day interval (range 5–10 days). Three-month stone-free rates were judged by plain X-ray and ultrasound.

Ergonomics

Based on a published questionnaire comparing laparoscopic and robot-assisted laparoscopic surgical ergonomics [30], the operator's discomfort during RA-RIRS was subjectively compared to their last 10 home institution cRIRS cases. All participating surgeons preferred standing-position cRIRS. A significant difference existed when comparing classic and RA-RIRS ergonomics for all questionnaire domains (Table 57.2; total questionnaire score 31.3 vs. 5.6 respectively; $P < 0.01$).

Radiation safety

Operating room personnel are at X-ray exposure risk in RA-RIRS (fluoroscopically guided stone procedure). Hence, fluoroscopic radiation exposure was measured during RA-RIRS for patient, anesthesiologist, and urologist, using RANDO phantoms, 19 thermoluminescent dosimeters (TLDs), and 21 TL ring dosimeters (TLRDs). The patient RANDO phantom with upper abdominal TLDs to measure the surface dose was placed on the operating table. The anesthesiologist and surgeon mannequins

Table 57.2 Ergonomic comparison of classic and RA-RIRS using a validated endourology questionnaire.

Surgeon	B.E.	A.Y.M.	K.S.	R.S.	Z.T.	J.J.R	O.T.	Mean
Age (years)	51	52	50	67	40	59	46	52.14
RIRS experience (years)	16	7	10	5	5	16	15	10.57
RIRS workload (hours/week)	10	12	15	7	10	6	18	11.14
cRIRS, complaints (0–5)								
Musculoskeletal pain	3	3	3	3	3	3	1	2.71
Neck pain	3	2	2	2	2	3	1	2.14
Shoulder stiffness	5	3	3	4	2	3	1	3.00
Arm pain	5	3	3	4	3	3	1	3.14
Forearm pain	5	3	3	3	3	4	1	3.14
Elbow stiffness	5	2	2	2	2	4	2	2.71
Hand pain	3	3	3	3	4	4	2	3.14
Wrist stiffness	3	4	4	3	3	4	1	3.14
Finger numbness	1	2	2	1	3	3	2	2.00
Back pain	3	1	1	2	3	3	1	2.00
Leg pain	2	2	2	2	3	4	2	2.43
Eye strain	0	2	2	2	3	2	1	1.71
Total score	**38**	**30**	**30**	**31**	**34**	**40**	**16**	**31.3**[a]
RA-RIRS, complaints (0–5)								
Musculoskeletal pain	0	1	0	0	0	0	0	0.14
Neck pain	0	0	0	0	1	1	0	0.29
Shoulder stiffness	2	0	0	1	0	0	0	0.43
Arm pain	2	1	1	1	0	0	0	0.71
Forearm pain	2	1	1	0	0	0	0	0.57
Elbow stiffness	2	0	0	0	0	0	0	0.29
Hand pain	2	0	0	0	1	1	1	0.71
Wrist stiffness	0	0	0	0	1	0	1	0.29
Finger numbness	0	1	1	1	1	1	1	0.86
Back pain	0	0	0	0	0	1	0	0.14
Leg pain	0	0	0	0	0	2	0	0.29
Eye strain	0	1	1	0	2	1	1	0.86
Total score	**10**	**5**	**4**	**3**	**6**	**7**	**4**	**5.6**[a]

[a] $P < 0.01$.
Source: [26]. Reproduced with permission of Elsevier.

were protected (0.5 mm lead apron and thyroid shield), and positioned near the operating table with eye, thyroid, extremity, and gonad region TLDs. The anesthesiologist mannequin was 1 m, the surgeon 0.74–0.8 m, and the Avicenna Roboflex console surgeon was 1.74–2.46 m from the fluoroscopy tube.

Retrospectively reviewed medical records revealed 30 seconds' mean cRIRS fluoroscopic screening time. Mean fluoroscopy tube potential and tube current were 66 kV and 4.99 mA, respectively, and were used to irradiate the RANDO phantom for 10 minutes (600 seconds) corresponding to 20 (600/30) RIRS operations, with a mobile multidirectional C-arm fluoroscopy unit.

In this study, for 600 seconds of fluoroscopic guidance time, the patient surface dose was 1.41 mSv (=70.5 μSv per operation), the anesthesiologist's exposure was 0.1 mSv (=5 μSv per operation), the patient-side surgeon was exposed to 0.11 mSv (=5.5 μSv) for left foot and 0.15 mSv (=7.5 μSv) for right foot. All radiation doses were below the 0.1 mSv (=5 μSv per operation) detection limit for the unprotected surgeon at the Avicenna Roboflex master console. In a urology department where 250 annual RIRS procedures take place, the annual mean dose equivalent for the anesthesiologist and patient-side urologist were calculated to be 1.25 and 1.63 mSv respectively. These preliminary results indicated that patient's and medical professional's radiation doses were quite low, but could be safely eliminated for the Avicenna Roboflex console surgeon without needing any lead protection whatsoever [31]. Self evidently, this has a significant beneficial impact on surgeon comfort and endurance.

Training study [32]

Five experts and novices were compared in classical versus RA-RIRS for complete stone fragmentation time in five cases. There was a longer average time for RA-RIRS versus cRIRS for experts (28.84 vs. 22.04 min) and vice versa for trainees (29.84 vs. 35.72 min), who were >13 minutes slower than experts in cRIRS. Trainees learned and approached expert RA-RIRS proficiency levels after only four trials in the bench model training setting.

Flexible ureterorenoscope and manipulator arm durability

Preliminary personal communication data (Dr R. Saglam) suggested that Avicenna Roboflex use at the Medicana Hospital, Ankara, Turkey, coupled to a first-generation Karl Storz Flex-XC yielded a scope durability of 42 cases with the first instrument coupled to early prototypes, and 210 RA-RIRS stone cases thereafter with multiple users, before scope electrical failure occurred in each instance. A dedicated team member plus Cidex sterlization techniques may have both contributed to some of this instrument longevity. Moreover, the second instrument was also used to demonstrate the Avicenna Roboflex at all major urological congresses over 3 years. There has only been one instance of MA malfunction due to water seepage into electronics in early trials, resolved by better custom drapes.

Discussion

Incremental cRIRS technology improvements over two decades have culminated in dual active endoscope deflection capability, dual-channel digital ureterorenoscopes, hybridized semirigid and coaxial flexible instruments [33], and now disposable/limited-use digital and fiber-optic scopes. Laser fiber technology has also improved with adjustable pulse duration and rounder tips to protect scope work channels better during introduction when new, coupled with a wide array of nitinol stone-retrieval accessories with allied techniques (LC clot [34], blue spritz, etc.). These developments have been actively disseminated by pioneering experts through didactic lectures and hands-on courses, under the aegis of all the major national and international urological societies including the Endourology Society, culminating in widespread cRIRS adoption [35]. Early cRIRS champions and experts have recently tackled more complex intrarenal pathologies, particularly renal stones >1.5 cm, as reflected in updated international European and American guidelines. However, cRIRS is not without its challenges, particularly in these complex cases (e.g. larger stone burden or multiple intrarenal and/or ureteral calculi). Ergonomic problems [36–38] (hand elbow, shoulder, neck, back, hips, knees, ankles) are related to wearing protective lead gowns, thyroid shields, and hand and eye protection in some cases, when performing standing or seated cRIRS on stools for long time periods, leading to operator fatigue. Further challenges include respiratory renal excursion, hindered working space, and the need to simultaneously use various foot pedals to control lasers and/or fluoroscopy equipment, while relying on allied team members to activate laser panel settings and between standby and active settings, or for irrigation adjustments and fluid bag changes, and simultaneously dealing with rapidly changing intraoperative circumstances and fleeting stone treatment opportunities which may influence ultimate success or failure. Together, these lead to cumulative operator fatigue amd physical exhaustion, particularly when treating several such challenging cases of over an hour each throughout the day. This has obvious

Table 57.3 Summary of cRIRS series in the last decade.

Study	Year	No. of patients	Stone size (cm)	Mean no. of procedures	% Stone-free rate
Mariani [39]	2007	16	≥4	2.4	88
Riley [40]	2009	22	3	1.8	90.9
Breda [9]	2009	27	>2	1.6	85
Bader [41]	2010	24	2.975	1.7	92
Hyams [42]	2010	120	2.4	?	98
Aboumarzouk [43] (meta-analysis)	2012	445	2.5	1.6	93.7
Takazawa [44]	2012	20	3.1 (2–5)	1.4	90
Cohen [45]	2013	145	2.9	1.6	87
Miernik [46]	2013	38	2.71	1.1	82

detrimental knock-on effects to fine motor skills, task performance, and precision, even in expert hands! This may result in premature termination of a planned procedure, double-J stent placement, and the inevitable consequence of staged treatment to render the patient stone free. This was validated by cRIRS treatment outcomes in expert hands this past decade (Table 57.3).

Consequently, an opportunity to implement mechanically controlled devices into cRIRS procedures was presented. Desai et al. first exploited this opportunity with the Sensei-Hansen Robotic Catheter System, a cardiology/vascular system, adapting it for RA-RIRS, testing it in pigs (one renal pelvic perforation) and then in 18 patients [4, 5] (0.5–1.5 cm renal stones). Their four-component device consisted of a master input device, a dual catheter system with an inner flexible steerable component, a remote inner catheter/manipulation system, and an electronic rack containing computer hardware, power supplies, and video distribution units. The robotic flexible catheter system had a 12/14 Fr outer catheter sheath and inner 10/12 Fr catheter guide. A passive optical fiberscope was inserted through the inner catheter guide lumen. Remote catheter system manipulation maneuvered the flexible fiberscope tip, glued in place within the inner guide. The larger outer sheath tip, positioned at the ureteropelvic junction to stabilize the inner navigation guide within the collecting system, allowed passenger fiberscope manipulation within the inner catheter guide. Of 18 patients only three minor complications (transient fever in two and limb paresis in one), three secondary PCNL for stone residual, and 89% 3 month CT excretory urogram stone-free rate were reported. This device has since been discontinued in urology.

The Avicenna Roboflex robotic system was developed to be specifically dedicated to RA-RIRS. It has tackled many of the ergonomic challenges of cRIRS. After a proof-of-concept phase [25] (IDEAL stage 1) and progression from prototype to working design (IDEAL stage 2a), Saglam et al. demonstrated safe, efficacious device deployment, with a short learning curve, and disseminated the technology among selected experienced endourologists with varying cRIRS expertise (IDEAL stage 2b), publishing data from the first seven's early cases (Table 57.1). RA-RIRS performed in a comfortable ergonomically sound seated position remote from the operating table eliminated the drawback of surgeon (±assistant) fatigue from prolonged standing between the patient's legs at the operating table. Additionally, the surgeon doesn't need to wear protective lead items, for the Avicenna Roboflex MCC surgeon seat can be parked at a suitable safe distance from the operating table as our preliminary studies have shown [31]. The cumulative benefits of these ergonomic stress relieving RA-RIRS aspects was subjectively scored by initial users in Saglam et al's *European Urology* publication [26], and reported significant superiority over cRIRS, a finding verified by this author's current personal series of 17 cases.

The robotic MA enhances and directly drives all mechanical FUR functions, providing a further level of external control beyond the inherent endoscope mechanics, but does not eliminate disadvantages inherent to the FUR deflection cable-drum design mechanism, leading to slightly lagged responses in fine up-and-down tip deflection. Custom-made endoscope hand-piece couplers (different for each manufacturer's scope model) can be made, (an advantage) and are attached directly to a specially designed master plate of the robotic MA. The hand-piece deflection lever is moved by computer-controlled micromotors in the coupler, which communicate with the MCC unit via a cable connector. The RA manipulator also enables two-point shaft stabilization, allowing safe bidirectional rotation, plus advancement and retraction of the fixed instrument hand piece. Thus, RA-RIRS can be performed using standard 10–12 or 12–14 Fr variable length UAS, although shorter length/wider lumen is preferred to allow maximum deflection and dust efflux at the lowest pressures. All endoscope movements can be fine-tuned and scaled to adjustable degrees through the MCC. This level of control is not possible manually in a sustained manner in cRIRS. The laser fiber actuator allows fine motorized forwards and backwards movements beyond the endoscope tip without moving the endoscope itself, with automatic repositioning to a baseline neutral position where it cannot damage the endoscope tip. This lends further operator-controlled precision to stone dusting performance, fragmentation, and ablation, by allowing the operator to maintain the optimal distance between fiber tip and target to maximize the photo-acoustic pulsed stone surface ablation without having to adjust the scope tip position every time. Tables 57.4 and 57.5 describe and compare the ergonomic demands of cRIRs to RA-RIRS.

A key goal for introducing surgical master/slave robotic devices is to reduce the cumulative surgical ergonomic stresses of long and arduous cRIRS procedures for complex and large renal stones. A comfortable environment potentially augments an individual surgeon's capabilities, improves quality and throughput, and provides a comfortable learning environment for the less experienced urologist/trainee endourologist. Hand/wrist/other ergonomic problems reported in up to one-third of endourologists were re-iterated by Saglam et al. [26]. Avicenna Roboflex provided a comfortable platform that significantly improved ergonomics after a short learning curve (subjective score 5.6 vs. 31.3, $P < 0.01$). The fatigued surgeon translates to higher complication rates, longer operating times, additional treatment sessions, and frequent repair of delicate expensive FURs.

Carey et al. [47] reported new FUR damage-repair rates of 8.1% (6% unusable) at a single tertiary center after 40–48 uses, mainly due to errant laser firing (36%) and excessive instrument torque (28%). In our own evaluation, cRIRS instrument durability in a tertiary referral center was increased to >100 cases [48] by using the semirigid instrument as the workhorse and having the FUR tip occupied by a laser fiber in full deflection mode for the shortest possible time. However, initial experience reported here by Saglam (personal communication), if verified by others, suggests much greater scope longevity in RA-RIRS compared to cRIRS. The Avicenna Roboflex design, requiring laser fiber insertion only in a straight scope position using a console based memory function, stepwise motorized advancement of the laser fiber, and force-controlled (maximal $1\,N/mm^2$) deflection of the scope with similar controlled rotation of the supported torque-free shaft outside the UAS, are just some of the features that should contribute to potential FUR longevity (partially offsetting robot costs cumulatively).

Possible Avicenna Roboflex limitations are current lack of tactile feedback (as with all master/slave robotic devices),

Table 57.4 Ergonomic demands of cRIRS.

Operative action	Extremity(ies) required	Performed by
FUR insertion	Fingers of both hands (at glans-access sheath hub, and FUR handpiece)	Surgeon
FUR deflection	Hand holding handpiece and thumb deflection lever; fingers of other hand at meatus-access sheath hub to maintain straight shaft for optimal deflection capability	Surgeon
FUR rotation	Hand-holding hand piece; fingers of the other hand rotating shaft at meatus	Surgeon
Fluoroscopy activation	Hand/foot	Radiology technician or certified surgeon
Multifunctional operating table or C-arm movement	Arms/hand, foot, and torso	Radiology technician or certified surgeon
Irrigation control	Thumb and hand	Nurse or assistant
Syringe (contrast-flush-aspiration)	Thumb and hand	Surgeon
Nitinol accessories insertion or activation	Thumb and index finger(s)	Surgeon
Laser fiber insertion, advancement, and retraction	Thumb and index finger	Surgeon
Laser settings	Index finger	Nurse or assistant
Laser ready, standby modes	Index finger	Nurse or assistant
Laser activation	Foot	Surgeon

Source: [26]. Reproduced with permission of Elsevier.

Table 57.5 Comparing control of cRIRS and RA-RIRS.

Feature	cRIRS	RA-RIRS
Surgeon's position	Standing between patient legs in lithotomy	Seated comfortably with arm rest at MCC
FUR insertion	Manually through UAS	Manually through UAS
FUR advancement, rotation	With both hands	MCC joysticks (2)
Fine regulation of deflection	Not available, manual attempt	MCC right joystick pin wheel
Laser fiber insertion	Manually through working channel	Manually through working channel
Laser fiber fine movements in and out	Manually through working channel	MCC touch screen control
Laser activation in ready mode	Foot pedal (standing), not fixed to floor by operating table	Red foot-pedal control (sitting), fixed to MCC floor (right)
Laser energy/frequency, standby/active mode adjustment	Manually at device	Manually at device
Fluoroscopy activation	Hand/foot pedal control, radiographer	White foot-pedal control (sitting), fixed to MCC floor (left)
Table or C-arm movement	Manually, anesthetist/radiographer	Manually, anesthetist/radiographer
Irrigation control	By irrigant bag height (nurse) and/or surgeon-controlled pump (syringe, hand or foot pump)	MCC touch screen control
Nitinol accessories, insertion/activation	Manually at scope work channel	Manually at scope work channel

Source: [26]. Reproduced and adapted with permission of Elsevier.

underpinning the enduring need of a certain degree of surgeon expertise using compensatory visual clues and precisely controlled movements, and spatial awareness of the scope in all three dimensions. This will change in the future as haptic feedback technology evolves, but is not as critical in RA-RIRS as compared for laparocopic surgery, as the FUR coupled to the MA is introduced and advanced up the ureter inside the lumen of a ureteral access sheath. Additionally, there is the issue of the two-dimensional image monitor screen for scope tip navigation, and problems with the continued need to use baskets for stone fragment extraction where dusting or pop-corning is not possible. Although some have debated whether cRIRS should aim at complete stone ablation by dusting, or whether larger fragments should be actively retrieved using a nitinol basket via the UAS, the need for the latter should be minimal except for harder large stones once fragments are sub-5 mm or in high frequency recurrent large stone formers with uncorrected underlying metabolic risk factors, thus avoiding the need for time consuming partial undocking from the MA shaft support feature. Finally, the device cost may become a significant issue, particularly with respect to financial restrictions of healthcare systems in austerity. Following the IDEAL framework, a multicenter multinational prospective randomized controled trial should be planned to provide more specific details about the potential advantages of RA-RIRS versus cRIRS and smaller access PCNL techniques, for medium–large or branched renal stones, using CT-based end points for stone-free rates.

Presently, of over 4000 companies, 150 have a market cap of > US$200 million, with $2 billion worth of mergers and acquisitions, and $1.3 billion equity funding in the robotics sector of the global economy, with Japan leading the way. Most of this investment is dominated by civilian drone technology, with a 122% compound annual growth rate for 3D printing, and 36% industrial robotics growth in China alone between 2008 and 2013.

As surgeons, we need the surgical tools of tomorrow, not as replacements for ourselves, but as a means to enhance our individual abilities in order to be our best selves without fear of fatigue, so as to deliver superior patient outcomes. With this in mind, many have asked if they really need an expensive tool such as a robotic device? The lab data perhaps suggest not, but the answer must surely be … only if it can deliver patient outcomes that are worth the premium price or ultimately lead to other cost savings (shorter operating time, lower operating room support personnel requirement, lower complication rates [intra-and postoperative], less operator fatigue leading to lower retreatment rates, less FUR breakage, shorter operating room times per stone volume unit disintegrated, for a given stone hardness, location, and collecting system configuration, and lower auxiliary procedure rates). Ideally, it should allow us to tackle bigger stones in difficult places in the urinary tract without making painful holes [49] or risk bleeding, improving on current stone-free rates, and still be able to send patients home safely in minimal discomfort the same day without fear of re-admission or retreatment.

New technology is "new" but never born perfect out of engineering development! After birth, it must pass through an evolutionary and clinical refinement process driven by a cadre of key experts collaborating with the engineering brains, by using it over a realistic time period in real-world settings, based on complexity and learning curve issues. During this time, views are often polarized, sometimes perjoratively depending on how it is presented and who the early adopters are. Nevertheless, it generally creates public awareness, which leads to excitement and debate, especially (as seen with the Da Vinci), when marketed directly to patients and providers by organizations with vested interests. Thus at a time of increasing healthcare consumption, bottlenecks, and fiscal constraints, any new technology must ultimately prove its worth rather than being just another example of fulfilling the prophecy of "the emperor's new clothes" [50]. This means that for all technology, there are price points for affordability and cost-benefit to be considered. To underpin these, there must be a high-quality evidence base. Currently, Avicenna Roboflex RA-RIRS is somewhat limited by two factors: current FUR design and ureteral lumen size for access and fragment removal. So with RA-RIRS we must ask ourselves, will this tool extend what we as expert surgeons can do for our patients today or in the near future? Does it enhance their, our, or our team's safety? Does it have future development potential and versatility inside of and beyond the urological specialty? And is it future-proofed for modifications that could lead to improved performance for a reasonable time period to make the high initial investment outlay viable? Will most people be able to afford it eventually? Will it allow acquisition of advanced skill sets across a wider spectrum of practitioners, trainees, and novices, and can these be honed to perfection outside the clinical working environment, or is it just another very expensive comfortable chair?

The answers to these questions will vary from unit to unit, and will depend on many factors such as skill sets and referral patterns. For example, you don't need Avicenna Roboflex if the majority of ureters you deal with will not readily accept a UAS, or the majority of stones you treat are large branched hard renal stones where PCNL may still be arguably superior! However, if one's goal is to maximize the control a surgeon has over their endourological working environment and potentially increase it in the future, improve ergonomics to reduce fatigue and allow increased quality and throughput other factors notwithstanding, reduce the need for invasive painful percutaneous surgical procedures in an increasingly elderly and obese population dynamic, afflicted by comorbidities and needing blood-thinning medications, in whom stone disease is increasing and has a higher recurrence rate, then RA-RIRS should certainly be a mouth-watering prospect. This is especially true in a training center with a tertiary referral practice of sufficient volume, where young surgeons are increasingly challenged in skills acquisition and transfer by reduced working hours. Together, they may provide a strong argument for expensive technology to be limited to regional centers to begin with.

Moreover, it certainly is a potential asset where endourological precision is key such as in the renal conservative management of upper urinary tract urothelial cancer, where this author has undertaken the first RA-RIRS case to date (see Video 57.1), or complex stone disease with reduced renal function that needs to be preserved to avoid dialysis, or for those at significant risk of bleeding complications (multiple puncture PCNL in high risk patients on blood thinning or antiplatelet medications that cannot safely be discontinued). Moreover, if by simply changing a coupling adaptor, the device becomes a flexible multi-specialty tool, it has the potential for real cost-effectiveness and becomes a viable part of the future hospital landscape beyond urology. Our young successors may be much safer (with regards to the long-term consequences of cumulative radiation exposure) and proficient much faster than this endourologist generation [32]. The heavy burden of wearing lead protection for the whole duration of our careers, with long-term impact on our vertebrae and attached musculature will finally be shed.

With surgical robotics, we are not yet at the stage where we have self-learning programmable autonomous systems like the proverbial autopilot that can fully operate aircraft from take off to landing. Will we ever want this in the human body shop? Only time will tell, depending on where processor and biosensor functions along with machine learning, drive us as physicians and surgeons. What is clear is that we are at the beginning of a global social robotic revolution and the future may bring us hybrid machines possessing ambient intelligence, which can bring lasting value to surgical procedure outcomes. Human empathy and creativity may be the last bastion against the rule of artificial intelligence. Quintessentially, human roles in medical care can be enhanced, leaving individuals with more time to care, teach, create, and innovate, by embracing technology and innovatively shaping it to human needs. The future is exciting indeed!

Acknowledgments

In the preparation of this chapter I am deeply indebted to Dr Remzi Saglam and Mr Sinan Kabakci for assistance in providing some historical figures, key aspects of unpublished information, and video-editing assistance.

References

1 Shao HM, Chen JY, Truong TK et al. A new CT-aided robotic stereotaxis system. *Proc Annu Symp Comput Appl Med Care* 1985; 13: 668–672.
2 Abbou CC, Hoznek A, Salomon L et al. Remote laparoscopic radical prostatectomy carried out with a robot. *Report of a case. Prog Urol* 2000;10:520–523.
3 Wolfram M, Bräutigam R, Engl T et al. Robotic-assisted laparoscopic radical prostatectomy: the Frankfurt technique. *World J Urol* 2003;21(3):128–132.
4 Desai MM, Aron M, Gill IS et al. Flexible robotic retrograde renoscopy: description of novel robotic device and preliminary laboratory experience. *Urology* 2008;72:42–46.
5 Desai MM, Grover R, Aron M et al. Robotic flexible ureteroscopy for renal calculi: initial clinical experience. *J Urol* 2011;186:563–568.
6 Rupel E and Brown R. Nephroscopy with removal of stone following nephrostomy for obstructive calculus anuria. *J Urol* 1941;46:177–179.
7 Preminger GM, Tiselius H-G, Assimos DG et al. 2007 guideline for the management of ureteral calculi. *Eur Urol* 2007;52:1610–1631.
8 Beiko DT and Denstedt JD. Advances in ureterorenoscopy. *Urol Clin North Am* 2007;34:397–408.
9 Breda A, Ogunyemi O, Leppert JT, and Schulam PG. Flexible ureteroscopy and laser lithotripsy for multiple unilateral intrarenal stones. *Eur Urol* 2009;55(5): 1190–1197.
10 Rassweiler JJ, Knoll T, Köhrmann K-U et al. Shock wave technology and application: an update. *Eur Urol* 2011;59:784–796.
11 Patel A and Fuchs GJ. Expanding the horizons of SWL through adjunctive use of retrograde intrarenal surgery: new techniques and indications. *J Endourol* 1997;11:33–36.
12 Knoll T, Jessen JP, Honeck P, Wendt-Nordahl G. Flexible ureterorenoscopy versus miniaturized PNL for solitary renal calculi of 10–30 mm size. *World J Urol* 2011;29:755–759.
13 Holden T, Pedro RN, Hendlin K et al. Evidence-based instrumentation for flexible ureteroscopy: a review. *J Endourol* 2008;22:1423–1426.
14 Somani BK, Aboumarzouk O, Srivastava A, and Traxer O. Flexible ureteroscopy: tips and tricks. *Urol Ann* 2013;5:1–6.
15 Monga M, Dretler SP, Landman J et al. Maximizing ureteroscope deflection: "play it straight". *Urology* 2002;60:902–905.
16 Bagley DH and Cubler-Goodman A. Radiation exposure during ureteroscopy. *J Urol* 1990;144:1356–1358.
17 Hellawell GO, Mutch SJ, Thevendran G et al. Radiation exposure and the urologist: what are the risks? *J Urol* 2005;174:948–952.
18 Kim KP, Miller DL, Berrington de Gonzalez A et al. Occupational radiation doses to operators performing fluoroscopically-guided procedures. *Health Phys* 2012;103:80–99.
19 Sabnis RB, Jagtap J, Mishra S, and Desai M. Treating renal calculi 1–2 cm in diameter with minipercutaneous or retrograde intrarenal surgery: a prospective comparative study. *BJU Int* 2012;110(8b):E346–E349.
20 Desai MR, Sharma R, Mishra S et al. Single-step percutaneous nephrolithotomy (microperc): the initial clinical report. *J Urol* 2011;186(1):140–145.
21 Desai J, Zeng G, Zhao Z et al. A novel technique of ultra-mini-percutaneous nephrolithotomy: introduction and an initial experience for treatment of upper urinary calculi less than 2 cm. *Biomed Res Int* 2013;490793: doi:10.1155/2013/490793.
22 Schoenthaler M, Wilhelm K, Hein S et al. Ultra-mini PCNL versus flexible ureteroscopy: a matched analysis of treatment costs (endoscopes and disposables) in patients with renal stones 10–20 mm. *World J Urol* 2015;33(10):1601–1605.
23 Datta SN, Solanki R, and Desai J. Prospective outcomes of ultra mini percutaneous nephrolithotomy: a consecutive cohort study. *J Urol* 2016;195(3):741–746.
24 Zeng G, Wan SP, Zhao Z et al. Super-mini percutaneous nephrolithotomy (SMP): a new concept in technique and instrumentation. *BJU Int* 2016:117(4):655–661.
25 Saglam R, Kabakci AS, Koruk E, and Tokatli Z. How did we designed and improved a new Turkish robot for flexible ureterorenoscopy. *J Endourol* 2012; 26(Suppl 1):A275, MP44-12.
26 Saglam R, Muslumanoglu AY, Tokatlı Z et al. New robot for flexible ureteroscopy: development and early clinical results (IDEAL Stage 1–2b). *Eur Urol* 2014;66(6):1092–1100.
27 Finch W, Johnston R, Shaida N et al. Measuring stone volume - three-dimensional software reconstruction or ellipsoid algebra formula? *BJU Int* 2014;113: 610–614.
28 Rampinelli C, Fiori E, Raimondi S et al. In vivo repeatability of automated volume calculations of small pulmonary nodules with CT. *Am J Roentgenol* 2009;192:1657–1661.
29 Patel SR and Nakada SY. Quantification of preoperative stone burden for ureteroscopy and shock wave lithotripsy: current state and future recommendations. *Urology* 2011;78:282–285.

30 Rassweiler JJ, Goezen AS, and Jalal AA. et al. A new platform improving the ergonomics of laparoscopic surgery: initial clinical evaluation of the prototype. *Eur Urol* 2012;61:226–229.
31 Patel A, Tokatlı Z, Parmaksız A, et al. Preliminary radiation dose evaluation of patient and medical professionals in robotic assisted retrograde intra-renal surgery with Roboflex Avicenna. *J Endourol* 2016;30(Suppl. 2):MP42-4:35.
32 Binbay M, Gokce I, Tokatli Z et al. A short learning curve of robotic assisted flexible ureteroscopy may help the trainees. *J Endourol.* 2014;28(Suppl. 1): MP10-02:24.
33 Gao X, Zeng G, Chen H et al. A novel ureterorenoscope for the management of upper urinary tract stones: initial experience from a prospective multicenter study. *J Endourol* 2015;29(6):718–724.
34 Patel A. Lower calyceal occlusion by autologous blood clot to prevent stone fragment reaccumulation after retrograde intra-renal surgery for lower calyceal stones: first experience of a new technique. *J Endourol* 2008;22(11):2501–2506.
35 Sanguedolce F, Liatsikos E, Verze P et al. Use of flexible ureteroscopy in the clinical practice for the treatment of renal stones: results from a large European survey conducted by the EAU Young Academic Urologists-Working Party on Endourology and Urolithiasis. *Urolithiasis* 2014;42(4):329–334.
36 Elkoushy MA and Andonian S. Prevalence of orthopedic complaints among endourologists are common and their compliance with radiation safety measures very important. *Endourology* 2011;25:1609–1613.
37 Healy KA, Pak RW, Cleary RC et al. Hand and wrist problems among endourologists are very common. *J Endourol* 2011;25(12):1905–1920.
38 Tjiam IM, Goossens RH, Schout BM et al. Ergonomics in endourology and laparoscopy: an overview of musculoskeletal problems in urology. *J Endourol* 2014;28(5):605–611.
39 Mariani AJ. Combined electrohydraulic and holmium:YAG laser ureteroscopic nephrolithotripsy of large (greater than 4 cm) renal calculi. *J Urol* 2007;177(1):168–173.
40 Riley JM, Stearman L, and Troxel S. Retrograde ureteroscopy for renal stones larger than 2.5 cm. *J Endourol* 2009;23(9):1395–1398.
41 Bader MJ, Gratzke C, Walther S et al. Efficacy of retrograde ureteropyeloscopic holmium laser lithotripsy for intrarenal calculi >2 cm. *Urol Res* 2010;38(5):397–402.
42 Hyams ES, Munver R, Bird VG et al. Flexible ureterorenoscopy and holmium laser lithotripsy for the management of renal stone burdens that measure 2 to 3 cm: a multi-institutional experience. *J Endourol* 2010;24(10):1583–1588.
43 Aboumarzouk OM, Monga M, Kata SG et al. Flexible ureteroscopy and laser lithotripsy for stones & gt >2 cm: a systematic review and meta-analysis. *J Endourol* 2012;26(10):1257–1263.
44 Takazawa R, Kitayama S, and Tsujii T. Successful outcome of flexible ureteroscopy with holmium laser lithotripsy for renal stones 2 cm or greater. *Int J Urol* 2012;19(3):264–267.
45 Cohen J, Cohen S, and Grasso M. Ureteropyeloscopic treatment of large, complex intrarenal and proximal ureteral calculi. *BJU Int* 2013;111(3 Pt B):E127–E131.
46 Miernik A, Schoenthaler M, Wilhelm K et al. Combined semirigid and flexible ureterorenoscopy via a large ureteral access sheath for kidney stones >2 cm: a bicentric prospective assessment. *World J Urol* 2014;32(3):697–702.
47 Carey RI, Gomez CS, Maurici G et al. Frequency of ureteroscope damage seen at a tertiary care center. *J Urol* 2006;176:607–610.
48 Defidio L, De Dominicis M, Di Gianfrancesco L et al. Improving flexible ureterorenoscope durability up to 100 procedures. *J Endourol* 2012;26(10):1329–1334.
49 Sabnis R, Ganesamoni R, Doshi A et al. Micropercutaneous nephrolithotomy (microperc) vs. retrograde intrarenal surgery for the management of small renal calculi: a randomized controlled trial. *BJU Int* 2013;112(3):355–361.
50 Yaxley JW, Coughlin GD, Chambers SK et al. Robot-assisted laparoscopic prostatectomy versus open radical retropubic prostatectomy: early outcomes from a randomised controlled phase 3 study. *The Lancet* 2016;388:1057–1066.