Robotic Flexible Ureteroscopy for Renal Calculi: Initial Clinical Experience

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Purpose: We report what is to our knowledge the initial clinical experience with remote robotic ureterorenoscopy and laser lithotripsy for renal calculi using a novel flexible robotic system.

Materials and Methods: After institutional review board approval and informed consent 18 patients with renal calculi underwent flexible robotic ureteroscopy. Study inclusion criteria were 5 to 15 mm renal calculi. Patients with ureteral calculi or obstruction, uncontrolled infection, renal insufficiency or solitary kidney were excluded from analysis. The flexible robotic catheter system was manually introduced into the renal collecting system over a guidewire under fluoroscopic control. All intrarenal maneuvers, including stone relocation and fragmentation into 1 to 2 mm particles, were done exclusively from the remote robotic console.

Results: All procedures were technically successful without conversion to manual ureteroscopy. Mean stone size was 11.9 mm, mean robot docking time was 7.3 minutes, mean stone localization time was 8.7 minutes, mean total robot time was 41.4 minutes and mean total operative time was 91 minutes. The mean visual analog scale rating on a scale of 1—worst to 10—best was 8.5 for robotic control, 9.0 for stability and 9.2 for fragmentation ease. There were no intraoperative complications. Postoperative complications included transient fever in 2 cases and temporary limb paresis in 1. One patient required secondary percutaneous nephrolithotomy for residual stone. Based on computerized tomogram/excretory urogram the complete stone clearance rate at 2 and 3 months was 56% and 89%, respectively. At 3 months all patients had stable renal function and unobstructed drainage.

Conclusions: We present a novel flexible robotic platform for retrograde ureteroscopic treatment for intrarenal calculi. Initial experience is encouraging.

Key Words: kidney, kidney calculi, endoscopy, robotics, instrumentation

Abbreviations and Acronyms

CT = computerized tomography

IVP = excretory urography

KUB = plain x-ray of kidneys, ureters and bladder

MID = master input device

RCM = remote catheter manipulator

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Study received institutional review board approval.

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ONGOING refinements in flexible ureteroscope technology, accessories and Ho:YAG laser lithotripsy have led to a widespread increase in the use of flexible ureteroscopy to treat small to medium renal calculi.[1,2] The ability to directly visualize a stone and relocate it to a favorable site for adequate fragmentation and subsequent drainage is an attractive advantage of flexible ureteroscopic laser lithotripsy for renal calculi. Efforts are ongoing to further improve deflection, enhance maneuverability and improve optical performance of current actively deflectable flexible ureteroscopes.[3]

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Recently the novel flexible Sensei® robotic catheter system was introduced for intracardiac applications. After making purpose specific software modifications we evaluated the technical feasibility and efficacy of this novel flexible robotic system for flexible ureterorenoscopy and Ho:YAG laser lithotripsy in the animal model.[4] We report the results of what is to our knowledge the first human technical feasibility trial using the flexible robotic system for ureteroscopic laser lithotripsy in 18 patients with renal calculi.

MATERIALS AND METHODS

After obtaining institutional review board approval 18 patients with renal calculi were enrolled for robotic flexible ureteroscopic laser lithotripsy for renal calculi. Patients with 5 to 15 mm renal stones were included in the study. Exclusion criteria included concomitant ipsilateral ureteral calculi, ipsilateral ureteral stricture or obstruction, documented active urinary tract infection, baseline renal insufficiency, a solitary kidney and anatomical renal anomalies. Although patients with bilateral renal calculi were included in analysis, only 1 side was treated using the robotic system. Contralateral calculi were treated as needed using conventional modalities at a separate session.

All patients underwent preoperative baseline hematology, serum biochemistry and urine culture sensitivity tests, noncontrast spiral CT and IVP. Positive urine cultures were adequately treated with appropriate antibiotics and all patients had a negative urine culture before surgery.

Mean patient age was 46 years (range 26 to 74) and mean body mass index was 25 kg/m^2 (range 19 to 32) (see table). There were 12 males and 8 procedures were done on the right side. All cases were prestented for 1 to 2 weeks preoperatively.

Demographic, operative and stone clearance data

Mean mm stone size (range)	11.8	(9–25)
No. stone site:		
Pelvis	4	
Upper calyx	1	
Middle calyx	1	
Lower calyx	9	
Multiple	3	
No. prior stone intervention (%)	68	(33)
Mean American Society of Anesthesiologists class	1	
Mean days prior stenting (range)	14.5	(5–30)
Mean mins (range):		
Total operative time	91.3	(60–130)
Robot docking	7.3	(4–18)
Stone localization	8.7	(1–36)
Total robot	41.4	(21–70)
No. stones relocated (%)	7	(38)
Fluid:		
Mean ml reabsorbed (range)	1,494.5	(3,783.33–2,288.88)
No. absorbed (pos ethanol test)	3	
Intraop complications	0	
Mean days hospital stay (range)	2.3	(2–7)
Mean wks duration of stenting (range)	4.2	(4–6)
No. postop complication:	1	
Paraparesis	2	
Febrile urinary tract infection		
No. stone clearance (%):		
Day 1 on KUB	8	(44)
Stent removal on KUB	12	(67)
2 Mos postop on CT	10	(56)
3 Mos postop on IVP	15	(89)
No. normal kidney function on IVP	18	
No. ancillary percutaneous nephrolithotomy	1	

Flexible Robotic System

The flexible robotic system consists essentially of 4 components, including 1) the surgeon console, including the liquid crystal display and MID, 2) the flexible catheter system, 3) the RCM and 4) the electronics rack. The surgeon console contains the MID, which is a 3-dimensional joystick that allows intuitive control of the tip of the steerable catheter. Robotic navigation can be performed in the endoscopic and fluoroscopic modes, which can be interchanged by a switch on the surgeon console. The liquid crystal displays on the console simultaneously show endoscopic and fluoroscopic views side by side. The system also has the capability of registering and showing preoperative imaging, such as CT, on the real-time display. The robotic flexible catheter system consists of an outer catheter sheath and an inner catheter guide with outer and inner diameters of 14Fr/12Fr and 12Fr/10Fr, respectively. A custom-built passive fiber-optic flexible ureteroscope with a 7.5Fr outer diameter and a 3.4Fr central working channel was inserted through the flexible robotic catheter system. Remote manipulation of the catheter system maneuvers the ureteroscope tip, which is glued in place to the inner guide. The space between the inner guide catheter and the flexible ureteroscope provides space for irrigation fluid inflow and the working channel provides space for irrigation fluid egress. The 14Fr/12Fr outer guide is essentially a stabilizing catheter with a tip that lies stationary at the ureteropelvic junction. The inner guide catheter is the catheter that navigates through the collecting system. The passive fiber-optic ureteroscope has a 7.5Fr tip diameter and protrudes just beyond the inner guide catheter. Thus, the tip of the active component of the robotic system is 7.5Fr with a 12Fr shaft outer diameter.

The guide catheter and ureteroscope have a maximum deflection of 270 degrees in all directions, which is not decreased by using accessories though the working channel. The robotic catheter manipulator is an arm that is attached to the operating table or floor mounted. It consists of 1 setup joint and mounts to attach the catheter sheath and guide. For flexible ureteroscopy an additional mount was created on the RCM to stabilize the ureteroscope in place. The electronic rack contains the computer hardware, power supplies and video distribution units.

Operative Procedure

All procedures were performed with the patient under general anesthesia. Initially cystoscopy was done and the preexisting Double-J® ureteral stent was exchanged for a 0.0035-inch hydrophilic wire. Using a dual lumen catheter a second safety wire was positioned in the renal collecting system. The robotic catheter system, consisting of the