



OPEN Robotic flexible ureteroscopy system, Zamenix R, demonstrates efficacy and safety in initial clinical evaluation for retrograde intrarenal surgery

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This initial clinical trial evaluated the efficacy and safety of the retrograde intrarenal surgery using the robotic flexible ureteroscopy system, Zamenix R, in a multi-center, prospective, single-arm study. A total of 47 adult Korean patients with one or more kidney stones, ranging in maximal size from 5 to 30 mm, were recruited, and 46 patients were included in the analysis. The median age of patients was 57.50 [IQR 48.25–63.00] years, with a median of 1.00 [IQR 1.00–2.00] stones per patient and a median maximal size of 13.70 [IQR, 10.00–16.00] mm and a volume of 349.65 [IQR 201.60–704.10] mm³. The stone-free rates were 93.48% (< 4 mm), 71.74% (< 2 mm), and 56.52% (zero stone), based on each respective stone-free definition, with no conversions to conventional surgery. The median operative time was 91.50 [IQR 64.25–113.75] minutes, with a median console time of 71.00 [IQR 39.25–92.75] minutes. Ureteral injuries occurred in 17.39% of cases, including 6.52% Grade I and 10.87% Grade II injuries, all related to manual insertion of a ureteral access sheath. The postoperative complication rate was 6.52%, with all cases being Grade II urinary tract infections. Laser ablation speed was higher for larger stones. The operators reported low levels of musculoskeletal fatigue and numbness. The results demonstrated the efficacy and safety of the robot-assisted flexible ureteroscopic surgery using Zamenix R. Further investigation is required, including a comparison with the standard of care and a larger sample size.

Keywords Kidney calculi, Ureteroscopy, Robotic surgical procedures, Clinical study

Technological advances have led to the increasing adoption of retrograde intrarenal surgery (RIRS) for kidney stones smaller than 2 cm¹. RIRS is favored for its minimally invasive nature and lower complication rates compared to alternative techniques. Despite these advantages, the procedure remains technically demanding due to several challenges. Operator fatigue from prolonged ureteroscope manipulation, the necessity for additional assistance with stone baskets, the risk of ureteral injury during stone retrieval, and the impact of patient respiratory motion during the laser lithotripsy are all critical factors that can compromise its safety and effectiveness. Furthermore, radiation exposure during the procedure presents an additional concern, especially for urologists. Additionally, musculoskeletal disorders are highly prevalent among urologists, often associated with the physical demand of endoscopic surgeries. These disorders frequently manifest as discomfort and chronic pain in the back, shoulders, neck, hands, and legs².

As RIRS evolves to address more complex stones, both patient and surgeon factors are being considered to improve the quality of surgical outcomes and ergonomical efficiency for surgeons performing RIRS³. Building on these considerations, the recent introduction of new robotic systems for flexible ureteroscopy (f-URS) has expanded the potential advantages of RIRS by enabling surgeons to perform the procedure with less radiation

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exposure, and improved ergonomic conditions, particularly in case with large/complex and multiple stones⁴. With less fatigue, robot-assisted RIRS allows for more time and ability for better inspection of all calyces and helps target stones more effectively⁵.

In this paper, we introduce Zamenix R, a novel robotic f-URS system designed to simplify the complexity of RIRS procedures and mitigate operator fatigue by providing ergonomic and precise robotic assistance in the manipulation of the ureteroscope, laser fiber, and stone retrieval basket. Its clinical feasibility and safety have been previously demonstrated in in-vivo animal studies using a porcine model^{6,7}. Here, we report the results of the first prospective single-arm clinical study evaluating the efficacy and safety of RIRS performed with the Zamenix R system.

Materials and methods

Design of clinical study

A multi-center, prospective, single-arm study was designed (Registry: World Health Organization International Clinical Trials Registry Platform, Clinical Research Information Service, <http://cris.nih.go.kr>, Identifier: KCT0007506). Forty-seven adult Korean patients with one or more kidney stones, ranging in maximum size from 5 to 30 mm were enrolled starting from January 4th, 2022, at Seoul National University Hospital and Yonsei University Severance Hospital. The inclusion and exclusion criteria are outlined in Table 1. This study aimed to include cases where, despite a stone's maximal diameter being 5 mm, the presence of multiple stones necessitated RIRS the most appropriate treatment when stone volume was considered. This study was approved by the institutional review board of the institutions. All methods were performed in accordance with relevant guidelines and regulations, and informed consent was obtained from all patients. Perioperative data were prospectively collected from two institutions, and two experienced RIRS specialists performed the surgery. Patient's demographic and baseline characteristics were recorded. Preoperative CT scans were used to analyze stone characteristics, including maximal stone size, total volume, stone density (in Hounsfield units), location, and the Seoul National University Renal Stone Complexity (S-ReSC) score⁸. The maximal stone size for multiple stones was defined as the sum of the maximal lengths of all stones. Stone volume was calculated using the ellipsoid formula, $\pi/6 \times \text{Length} \times \text{Width} \times \text{Height}$, where the length, width, and height are the maximum dimensions of the stone measured on computerized tomography (CT) images. The primary outcome was the stone-free rate, defined as the absence of visible stones or residual stones < 4 mm on a CT scan one month after surgery. Secondary outcomes included operation time, ureteral injury rate, complication rate, operator's fatigue and numbness, conversion rate, and laser ablation speed. Operation time was subdivided into anesthesia time, operative time, and console time. Operative time was defined as the duration from the initial insertion of the cystoscope to the placement of the stent or Foley catheter at the end of the procedure. Console time was defined as the duration from the insertion of the f-URS to the completion of stone removal. Ureteral injury was evaluated in three scenarios: fluoroscopic inspection following guidewire insertion, endoscopic inspection of the proximal ureter between the proximal tip of the ureteral access sheath (UAS) and the ureteral pelvic junction (UPJ) immediately after UAS placement, and endoscopic inspection of the entire ureter during UAS removal following the robotic procedure. Ureteral injury was subsequently classified according to the method proposed by Traxer et al.⁹. Postoperative complications were observed during the one-month follow-up period and evaluated using the Clavien-Dindo classification¹⁰. Operator's fatigue and numbness were assessed using a 5-point Likert scale (1-point: very high fatigue and numbness, 5-point: very low fatigue and numbness). Fatigue was evaluated for ten body parts: shoulder, elbow, wrist, hand, thumb, neck, waist, leg, ankle, and sole. Numbness was evaluated for three body parts: wrist, hand, and thumb. Laser ablation speed was calculated as the total stone volume (mm³) divided by the console time (minutes).

Robotic f-URS system, Zamenix R

Zamenix R, developed by Roen Surgical Inc. (Daejeon, Korea), is a robotic f-URS system specifically designed for RIRS, as shown in Fig. 1. The Patient cart is compatible with a commercial f-URS. A dedicated stone retrieval

| Inclusion criteria |
|---|
| Adults between the ages of 19 and 80 years old who require RIRS due to renal stones that are difficult to remove naturally through non-surgical treatment |
| They must have one or more renal stones with a maximum size between 5 mm and 30 mm. If the maximal stone volume is < 10 mm, only multiple stones were included |
| They must voluntarily decide to participate in this clinical trial and provide written consent |
| They must be willing to comply with the clinical trial protocol |
| Exclusion criteria |
| Those who cannot discontinue anti-coagulants or anti-platelet drugs, excluding aspirin |
| Those who have bilateral stones and who require simultaneous removal |
| Those who must undergo other interventional surgeries upon RIRS, such as for prostatic hypertrophy, ureteropelvic junction obstruction, ureteral stricture, ureteral carcinoma, calyceal diverticulum, and others |
| Those who would have difficulties to undergo RIRS due to abnormalities in the anatomical structure of the ureter |
| Those who underwent renal replacement therapy, through transplantation |
| Those who were diagnosed with chronic kidney disease |
| Those with active urinary tract infection (UTI) |
| Pregnant women |
| Those who are hypersensitive to contrast agents and whose responses are difficult to control |
| Those who have difficulties in undergoing local and general anesthesia |
| Those who are currently participating or have participated in another clinical trial within 30 days from the screening date |
| Those who may otherwise affect the results and are considered unfit for this clinical trial, upon the discretion of the investigator |

Table 1. Inclusion and exclusion criteria.

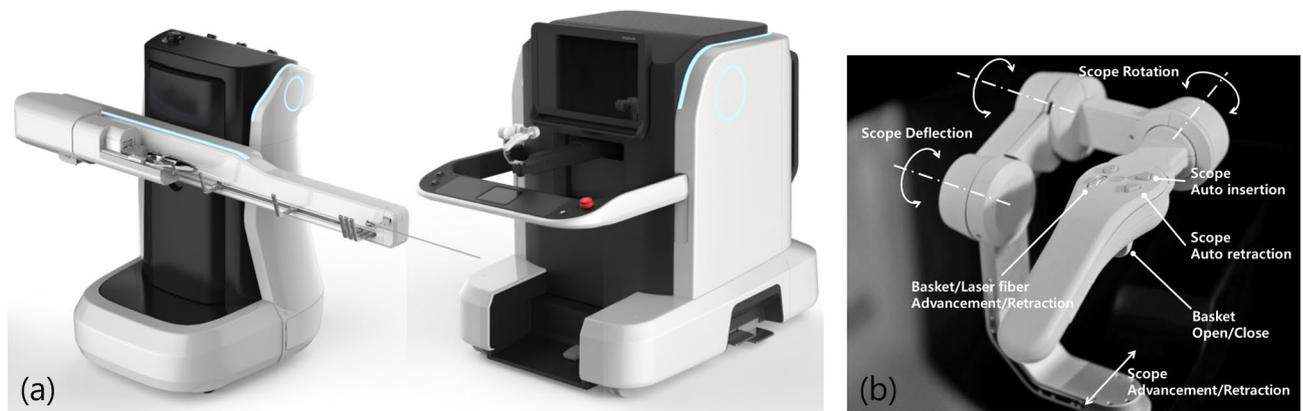


Fig. 1. The robotic flexible ureteroscopy system Zamenix R. **(a)** Appearance of surgeon console and patient cart. **(b)** The structure and function of the handle controller.

basket and a commercial laser fiber can also be attached to the slave robot, allowing them to be inserted into the ureteroscope's working channel. The surgeon console, which the operator uses while seated, provides an enlarged image from the ureteroscope image and a handle controller that enables remote control the ureteroscope's advancement/retraction, rotation, and deflection, as well as the advancement/retraction of the laser fiber and advancement/retraction and open/close of the stone retrieval basket. These features allow a single operator to perform the entire surgical procedures in an ergonomic and comfortable posture. Additionally, teleoperation permits the operator to be positioned behind a radiation shielding barrier, thus protecting the body from radiation exposure without the need to wear heavy lead aprons, vests, or collars. Furthermore, the robot includes two advanced functions that can enhance the efficiency and safety of stone retrieval: an automatic navigation function that records ureteroscope motion to re-access previously reached renal calyces, and a safety alarm that detects the grasping of an oversized stone, which could potentially collide with the UAS during extraction.

Robot-assisted RIRS procedure

All patients were pre-stented prior to the procedure. During procedure, the patient cart was draped, and the patient was placed in the lithotripsy position under general anesthesia. The patient's right leg was positioned slightly higher than the left leg to accommodate the placement of the robotic arm. A guidewire and UAS were manually inserted into the patient's urinary tract by the operator or assistant. In all cases, the Navigator HD UAS (Boston Scientific, Marlborough, Massachusetts, USA) with an 11/13Fr diameter was used. The length of the UAS was 36 cm for female patients, while both 36 cm and 46 cm were used for male patients. The distal tip of the UAS was positioned at the upper ureter, approximately 2 cm below the ureteropelvic junction. The patient cart was then docked to the UAS. A commercial f-URS (LithoVue, Boston Scientific, Marlborough, Massachusetts, USA) and a laser fiber or stone retrieval basket were mounted on the robot arm of the patient cart. The operator then sat at the console and operated the ureteroscope and instruments. The ureteroscope was inserted into the patient's kidney and the stone was disintegrated using the laser or retrieved using the stone retrieval basket. Holmium: Yttrium-Aluminum-Garnet laser (Versapulse PowerSuite 100 W, Boston Scientific, US) was used in all cases. Laser settings were as follows: 0.5 J and 30–40 Hz for dusting, 1 J and 10 Hz for fragmentation, and 1 J and 20 Hz for pop-dusting. An infusion pump was used for irrigation throughout the procedure. The pressure for continuous irrigation was typically set at 40 mmHg and increased to 70 mmHg during basketing. If necessary, pulsatile irrigation was used by connecting a syringe to the working channel of the f-URS. After the stone removal was completed, the robot arm was undocked, and the ureteroscope and UAS were manually removed from the patient, followed by a visual inspection for ureteral injury assessment. The operator or assistant then manually inserted a ureteral stent and a urethral Foley catheter.

Statistical analysis

Continuous data are presented as median and Inter Quartile Range (IQR) [Q1–Q3]. Categorical data are presented as frequency and percentages. All statistical analyses were performed using SAS software (SAS Institute, US). A p-value of less than 0.05 (<0.05) was considered statistically significant.

Results

Out of the 47 patients initially enrolled in this clinical trial, one patient dropped out prior to the surgery. Consequently, a total of 46 patients who underwent robot-assisted RIRS were included in the analysis, as shown in Fig. 2. The baseline demographics of the patients are summarized in Table 2, with a median age of 57.50 [IQR 48.25–63.00] years. The median number of stones was 1.00 [IQR 1.00–2.00], with a median maximal size of 13.70 [IQR, 10.00–16.00] mm and a volume of 349.65 [IQR 201.60–704.10] mm³. The median Hounsfield unit was 881.10 [IQR 719.40–1093.85]. Blood test results, including White Blood Cell (WBC) and C-Reactive Protein (CRP), as well as urinalysis, were all confirmed to be negative, with no associated symptoms reported. All four patients with clinically insignificant urine culture results were prescribed second-generation cephalosporins as prophylactic antibiotics prior to surgery.

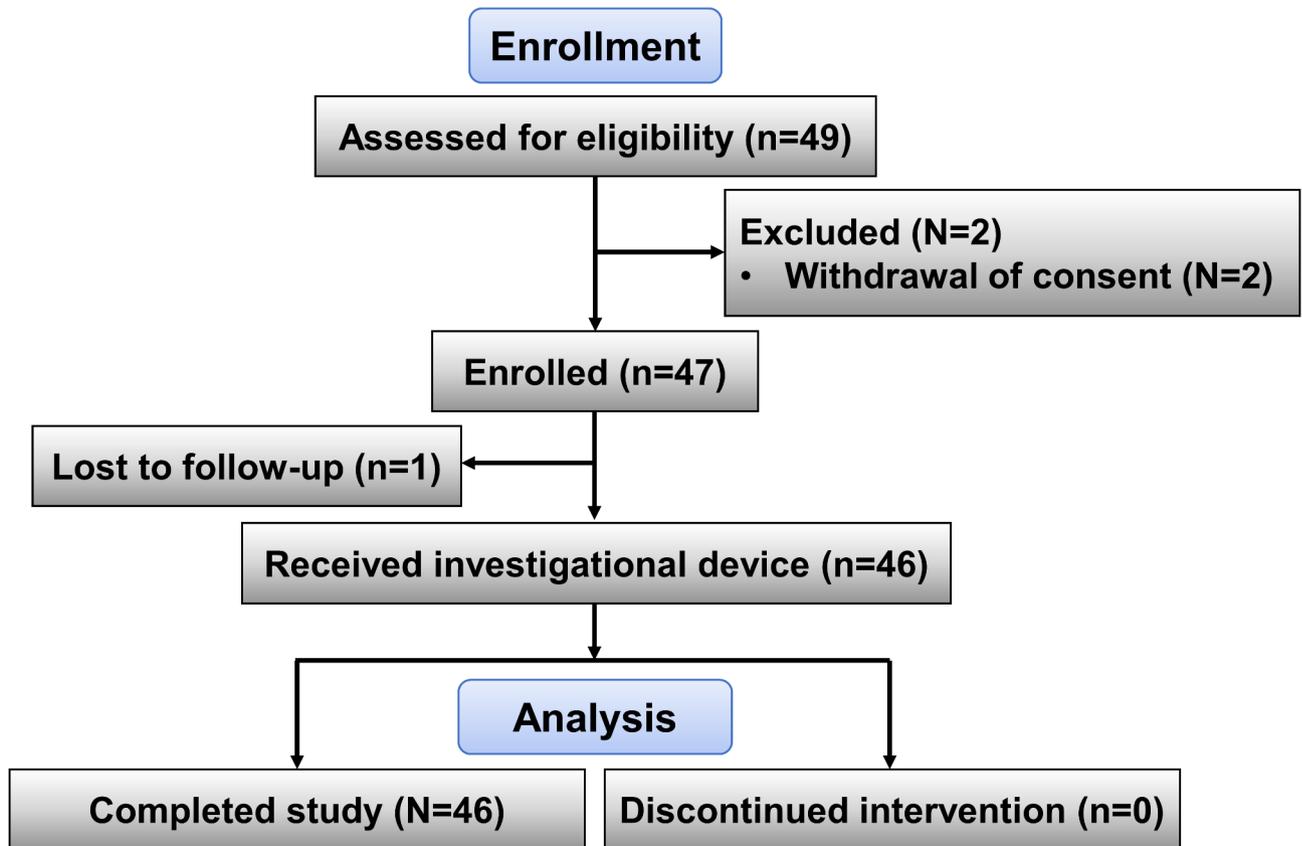


Fig. 2. Flowchart diagram of the clinical study.

The surgical outcomes are detailed in Table 3. The stone-free rates were 93.48% (< 4 mm), 71.74% (< 2 mm), and 56.52% (zero stone), based on each respective stone-free definition. Additionally, the median number and total volume of residual stone were 2 [IQR 1.00–3.25] and 8.75 [IQR 4.00–22.00] mm³, respectively. No cases required conversion to conventional surgical methods, and no intraoperative complication leading to the cessation of surgery occurred. The median operative time was 91.50 [IQR 64.25–113.75] minutes, with a console time of 71.00 [IQR 39.25–92.75] minutes. Draping and docking of the patient cart took less than 15 min on average and were included in the operative time. The incidence of ureteral injury was 6.52% (3 cases) for Grade I injuries and 10.87% (5 cases) for Grade II injuries. No contrast leakage occurred during retrograde pyelography following guidewire insertion. After UAS placement, three cases of ureteral injuries were observed at the proximal ureter, between the proximal tip of the UAS and the UPJ. During UAS removal, an additional five cases of ureteral injury were identified in the proximal, mid, and distal ureter, areas covered by UAS. These injuries were attributed to manual UAS insertion. All of these injuries resolved with the placement of a ureteral stent for 2–4 weeks. No ureteral strictures were observed during follow-up in any patient with non-contrast kidney CT scans conducted 2–3 months postoperatively. Additionally, retrograde pyelography was performed during ureteral stent removal to rigorously assess the presence of leakage at the ureteral injury site. The postoperative complication rate during the one-month follow-up period was 6.5%, which includes three cases of Grade II urinary tract infections. All patients without postoperative complications were discharged on postoperative day 1. The patients with postoperative urinary tract infections were treated with medication and discharged within five days. The laser ablation speed was higher for larger stones.

Table 4 presents the operator's fatigue and numbness associated with robot-assisted RIRS. Two operators reported low levels of fatigue and numbness after performing robot-assisted RIRS.

Discussion

The Zamenix R system has demonstrated the ability to safely complete the surgery and has been successfully applied to routine RIRS procedures. A key feature that distinguishes the Zamenix R system from conventional RIRS is its ergonomically integrated control of the ureteroscope, stone retrieval basket, and laser fiber, enabling a single operator to perform key procedures. In our experience, it provided surgeons with a more comfortable and less fatiguing clinical environment, more stable and precise control of the ureteroscope and instruments, and constant efficiency regardless of the assistant's experience, which were critical for maintaining surgical performance regardless of prolonged operation time and case difficulties. Particularly, the efficiency of robot-assisted RIRS is expected to be maximized in cases involving larger stones, as higher laser ablation efficiency was obtained in larger stones.

| Variables | Total (N = 46, Median (IQR)) |
|------------------------------------|------------------------------|
| Baseline characteristics | |
| Age (years) | 57.50 [48.25–63.00] |
| Gender, Male, N (%) | 24 (52.17) |
| Height (cm) | 163.50 [158.00–171.15] |
| Weight (kg) | 67.50 [59.55–74.65] |
| BMI (kg/m ²) | 25.25 [23.92–27.70] |
| Hydronephrosis, N (%) | 2 (4.35) |
| Preoperative ESWL, N (%) | 8 (17.39) |
| Preoperative PCN, N (%) | 1 (2.17) |
| Preoperative RIRS, N (%) | 2 (4.35) |
| Urinary tract infection, N (%) | 15 (32.61) |
| Diabetes mellitus, N (%) | 11 (23.91) |
| Hypertension, N (%) | 24 (52.17) |
| Stone characteristics | |
| Calcium oxalate monohydrate, N (%) | 36 (78.26) |
| Uric acid, N (%) | 4 (8.70) |
| Carbonate apatite, N (%) | 2 (4.34) |
| Ureteropelvic junction, N (%) | 4 (8.70) |
| Renal pelvis, N (%) | 30 (65.22) |
| Upper calyx, N (%) | 3 (6.52) |
| Mid calyx, N (%) | 3 (6.52) |
| Lower calyx, N (%) | 13 (28.26) |
| Infundibulo-Pelvic Angle (IPA) (°) | 64.27 [48.25–75.64] |
| Radiolucent stone, N (%) | 13 (28.26) |
| Diverticular stone, N (%) | 2 (4.35) |
| Parenchymal stone, N (%) | 5 (10.87) |
| S-ReSC Score | 1.00 [1.00–2.00] |
| Low score (1–2), N (%) | 37 (80.43) |
| Intermediate score (3–4), N (%) | 7 (15.22) |
| High score (>4), N (%) | 2 (4.35) |
| Total number of stone, N (%) | 1.00 [1.00–2.00] |
| Single stone, N (%) | 32 (69.57) |
| Multiple stone, N (%) | 14 (30.43) |
| Maximal stone size (mm) | 13.70 [10.00–16.00] |
| Stone volume (mm ³) | 349.65 [201.60–704.10] |
| Hounsfield unit | 881.10 [719.40–1093.85] |

Table 2. Patients' baseline characteristics and stone characteristics.

Literature on conventional RIRS with similar inclusion criteria and stone-free status definition to those in our study reported stone-free rates ranging from 86.5 to 90.0% (≤ 3 mm or < 4 mm), and complication rates ranging from 8.3–13.5%^{11–13}. Additionally, a systematic review reported a stone-free rate of 84.8% (< 4 mm) and a complication rate of 13.3% for conventional RIRS¹⁴. Although direct comparisons are limited due to differences in study protocols, evaluation criteria, and clinical settings, robot-assisted RIRS in this study demonstrated satisfactory efficacy and safety.

Due to ongoing technological advancements, RIRS has expanded its indications to treat nearly all cases of urinary stones, owing to its high stone-free rate and favorable safety profile. However, RIRS procedures still present ergonomic challenges, as surgeons must maintain uncomfortable, fixed positions for extended periods while handling heavy equipment and performing repetitive movements. This issue is particularly pronounced when dealing with multiple stones or stones in difficult-to-access areas, leading to significant physical strain on urologists. During RIRS procedures, the surgeon must stabilize the position of the endoscope while twisting and rotating their wrist, and simultaneously controlling the endoscope and laser devices with foot pedals. This often results in continuous strain and discomfort in both the hands and feet^{15,16}. The robot-assisted RIRS demonstrated that through ergonomic control of scope and instruments while seated without wearing radiation protective gear, and with automated ureteroscopy driving, it can minimize musculoskeletal pain and fatigue. Additionally, surgeons typically operate close to radiation sources, but introduction of robot-assisted surgery allows for greater distance from the radiation source and use of a radiation shield barrier, thereby minimizing exposure^{17,18}.

| Variables | Total (N= 46, Median (IQR)) |
|---|-----------------------------|
| Stone-free rate, N (%) | |
| Clinically stone free (residual stones with a maximum diameter of < 4 mm) | 43 (93.48) |
| Clinically stone free (residual stones with a maximum diameter of < 2 mm) | 33 (71.74) |
| Clinically stone free (zero stone) | 26 (56.52) |
| Operation time (min) | |
| Anesthesia time (min) | 122.50 [91.25–143.75] |
| Operative time (min) | 91.50 [64.25–113.75] |
| Console time (min) | 71.00 [39.25–92.75] |
| Ureteral injury rate, N (%) | |
| Grade 0 | 38 (82.61) |
| Grade I | 3 (6.52) |
| Grade II | 5 (10.87) |
| Grade III | 0 (0.00) |
| Grade IV | 0 (0.00) |
| Postoperative complication rate, N (%) | |
| Grade I | 0 (0.00) |
| Grade II | 3 (6.52) |
| Grade III | 0 (0.00) |
| Grade IV | 0 (0.00) |
| Grade V | 0 (0.00) |
| Conversion rate, N (%) | 0 (0.00) |
| Laser ablation speed (mm ³ /min) | 5.85 [2.92–9.88] |
| Stone size with a maximum diameter ≥ Median (13.70 mm) | 8.47 [5.18–13.57] |
| Stone size with a maximum diameter < Median (13.70 mm) | 4.23 [2.69–6.73] |

Table 3. Surgical outcomes of robot-assisted RIRS using Zamenix R.

| Variables | Score* |
|-----------|------------------|
| Fatigue | |
| Shoulder | 5.00 [5.00–5.00] |
| Elbow | 4.50 [4.25–4.75] |
| Wrist | 5.00 [5.00–5.00] |
| Hand | 4.50 [4.25–4.75] |
| Thumb | 4.00 [4.00–4.00] |
| Neck | 4.50 [4.25–4.75] |
| Waist | 5.00 [5.00–5.00] |
| Leg | 5.00 [5.00–5.00] |
| Ankle | 5.00 [5.00–5.00] |
| Sole | 5.00 [5.00–5.00] |
| Numbness | |
| Wrist | 5.00 [5.00–5.00] |
| Hand | 5.00 [5.00–5.00] |
| Thumb | 4.50 [4.25–4.75] |

Table 4. Surgeon's fatigue and numbness score. *1-point: very high fatigue and numbness, 5-point: very low fatigue and numbness.

During RIRS, kidney movement caused by respiration and mechanical ventilation presents a challenge, potentially leading to stone displacement and difficulty in accurately targeting stones with the laser. This can prolong surgery and increase the risk of complications. Techniques to control organ motion are crucial for effective treatment and minimizing tissue damage. Studies suggest that reducing kidney movement through adjustments in respiratory rate and tidal volume improves stone fragmentation¹⁹. However, maintaining precision during the procedure is difficult due to surgeon fatigue and hand tremors. When performing laser lithotripsy, the surgeon must simultaneously manipulate the endoscope and laser while compensating for respiratory motion. In our experience, however, with the Zamenix R system, the surgeon can concentrate solely on managing the laser's response to respiratory movements because the ureteroscope and laser fiber are stably

positioned and precisely adjustable through robotic manipulation. This could reduce the risk of kidney tissue injury due to laser contact.

The incidence of ureteral injury was relatively high in our study, despite all patients having undergone pre-stenting. In actual clinical practice, particularly in cases of ureteral narrowing, options such as a 10/12Fr UAS or thinner f-URS may be utilized. However, in this clinical trial, the degree of ureteral narrowing was not strictly evaluated, and only the 9.5Fr f-URS and 11/13Fr UAS were used. The primary objective of the study was to assess the efficacy and safety of the robotic procedure, which introduced certain limitations. Advancements, including the enhanced compatibility with a wider variety of f-URS and the investigation of robotic procedures such as performing RIRS without a UAS, may further reduce the likelihood of ureteral injury.

Since the first attempt of robot-assisted RIRS in 2011²⁰, several robot-assisted RIRS systems, including Avicenna Roboflex, Ily, and Monarch have developed. These systems offer advantages in terms of surgeon ergonomics and ease of control, and early clinical results have reported promising outcomes, with satisfactory stone-free and complication rates^{16–18,21}. Key features that distinguish the Zamenix R system from other robotic systems include: integrated control of the stone retrieval basket and the laser fiber, enabling the execution of all essential surgical procedures without the need for additional manual intervention; a gimbal handle controller that provides agile and simultaneous control of the ureteroscope and instruments; and assistive functions, such as stone size estimation and automated ureteroscope driving, which have the potential to enhance the efficiency and safety of the procedure. However, further investigation is required to confirm these benefits.

Nonetheless, the robotic system has room for improvement. First, the operator is positioned away from the surgical site, thus assistance from a surgical assistant is necessary to adjust the irrigation fluid and monitor the temperature increase of the irrigation outflow during laser use. Second, the size of the robot is still relatively large, which may make it less suitable for crowded operating theaters. Third, the lack of tactile feedback from the ureteroscope remains a limitation. Although this study was completed without any safety issues related to the absence of tactile feedback, it could pose challenges in more complex cases, such as those involving narrow and tortuous ureters and kidneys. Following the clinical trials, the manufacturer is preparing an improved version of the robot to address these issues.

Limitation

This study has several limitations, the first of which is its single-arm design, which lacks a comparison with the current standard of care. The current findings regarding the merits and limitations of the robot-assisted RIRS are primarily based on users' observation, and therefore, further comparative studies are required to quantitatively evaluate these aspects. Additionally, the small sample size and limited number of participating operators necessitate further research to enable the generalization of the findings. Lastly, all the patients in this study underwent pre-stenting. This was because the primary objective of the study was to evaluate the safety and efficacy of the robotic procedure for RIRS. As such, pre-stenting was included in the study protocol to minimize the risk of UAS insertion failure due to ureteral narrowing. In actual clinical practice, however, surgeons do not perform pre-stenting in all cases. We believe that future studies focusing on real-world evidence will provide insights regarding outcomes in patients without pre-stenting. Nonetheless, this initial clinical study is of significant importance as it evaluates the clinical feasibility, safety, and efficacy of the newly developed Zamenix R robotic system, serving as a crucial first step toward the further optimization of the technology, procedures, and patient selection.

Conclusion

The newly developed robotic f-URS system, Zamenix R, demonstrated its efficacy and safety in retrograde intrarenal surgery in the initial clinical trial. With further technological advancement and accumulation of clinical experience, it may offer a safe, effective treatment option for stone management, potentially overcoming the limitations of conventional, manually performed RIRS.

Data availability

The datasets used during the current study available from the corresponding author on request.

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References

- Soderberg, L. et al. Percutaneous nephrolithotomy vs retrograde intrarenal surgery for renal stones: a Cochrane review. *BJU Int.* **133**, 132–140 (2024).
- Tjiam, I. M. et al. Ergonomics in endourology and laparoscopy: an overview of musculoskeletal problems in urology. *J. Endourol.* **28**, 605–611 (2014).
- Sinha, M. M. et al. Technical aspects and clinical outcomes of robotic ureteroscopy: is it ready for primetime?? *Curr. Urol. Rep.* **24**, 391–400 (2023).
- Gauhar, V. et al. Robotic retrograde intrarenal surgery: A journey from back to the future. *J. Clin. Med.* **11**, 5488 (2022).
- Rassweiler-Seyfried, M. C. et al. Robot-assisted flexible ureterorenoscopy: state of the Art in 2022. *Mini-invasive Surg.* **6** (2022).
- Han, H. et al. Feasibility of laser lithotripsy for midsize stones using robotic retrograde intrarenal surgery system EasyUretero in a Porcine model. *J. Endourol.* **36**, 1586–1592 (2022).
- Kim, J. et al. In vivo feasibility test of a new flexible ureteroscopic robotic system, EasyUretero, for renal stone retrieval in a Porcine model. *Yonsei Med. J.* **63**, 1106 (2022).
- Jung, J. W. et al. Modified Seoul National University Renal Stone Complexity score for retrograde intrarenal surgery. *Urolithiasis* **42**, 335–340 (2014).
- Traxer, O. & Thomas, A. Prospective evaluation and classification of ureteral wall injuries resulting from insertion of a ureteral access sheath during retrograde intrarenal surgery. *J. Urol.* **189**, 580–584 (2013).

10. Dindo, D. The Clavien–Dindo classification of surgical complications. *Treat. Postoper. Compl. After Dig. Surg.* 13–17 (2014).
11. El-Nahas, A. R. et al. Flexible ureterorenoscopy versus extracorporeal shock wave lithotripsy for treatment of lower pole stones of 10–20 mm. *BJU Int.* **110**, 898–902 (2012).
12. Kumar, A. et al. A prospective randomized comparison between shock wave lithotripsy and flexible ureterorenoscopy for lower caliceal stones ≤ 2 cm: A Single-Center experience. *J. Endourol.* **29**, 575–579 (2015).
13. Javanmard, B. et al. Retrograde intrarenal surgery versus shock wave lithotripsy for renal stones smaller than 2 cm: A randomized clinical trial. *Urol. J.* **13**, 2823–2828 (2016).
14. Sethawong, V. et al. Extracorporeal shock wave lithotripsy (ESWL) versus percutaneous nephrolithotomy (PCNL) or retrograde intrarenal surgery (RIRS) for kidney stones. *Cochrane Database Syst. Rev.* **8**, CD007044 (2023).
15. Gabrielson, A. T. et al. A global survey of ergonomics practice patterns and rates of musculoskeletal pain among urologists performing retrograde intrarenal surgery. *J. Endourol.* **36**, 1168–1176 (2022).
16. Farré, A. et al. Robot-assisted retrograde intrarenal surgery: first clinical experience with the ILY[®] system. *BJU Int.* (2024).
17. El-Hajj, A., Abou Chawareb, E., Zein, M. & Wahoud, N. First prospective clinical assessment of the ILY[®] robotic flexible ureteroscopy platform. *World J. Urol.* **42**, 143 (2024).
18. Salah, M. et al. Optimizing outcome reporting after robotic flexible ureteroscopy for management of renal calculi: introducing the concept of tetrafacta. *J. Robot. Surg.* **18**, 128 (2024).
19. Kourmpetis, V. et al. Toward respiratory-gated retrograde intrarenal surgery: a prospective controlled randomized study. *J. Endourol.* **32**, 812–817 (2018).
20. Desai, M. M. et al. Robotic flexible ureteroscopy for renal calculi: initial clinical experience. *J. Urol.* **186**, 563–568 (2011).
21. Landman, J. et al. Initial clinical experience with a novel robotically assisted platform for combined mini-percutaneous nephrolithotomy and flexible ureteroscopic lithotripsy. *J. Urol.* **212**, 483–493 (2024).

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Author contributions

J.K. contributed to the study design, data analysis and manuscript drafting. H.P. was involved in data analysis and manuscript drafting. D.-S.K. participated in the development of an investigational device and critical revision of the manuscript. J.Y.L. was responsible for the study design, data acquisition and interpretation. S.Y.C. was responsible for study design, data acquisition and interpretation, and supervised the entire study.

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Ethics declarations

Ethics approval and consent to participate

This study was approved by the institutional review boards of Seoul National University Hospital (IRB: 2108-132-1246) and Yonsei University Severance Hospital (IRB: 1-2021-0067). All methods were carried out in accordance with relevant guidelines and regulations. Informed consent was obtained from all patients.

Competing interests

The corresponding author has received research funding from the company. Joonhwan Kim is an employee of Roen Surgical, Inc. and Dong-Soo Kwon is the CEO of Roen Surgical, Inc. The authors declare no competing interests.

Additional information

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