



Robot-assisted laparoendoscopic single-site upper urinary tract surgery with da Vinci Xi surgical system: Initial experience

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Purpose: The da Vinci Xi robot surgical system was newly released with several upgrades and modifications made to its previous Si platform; to further enhance the capabilities to carry out minimally invasive surgery. This study aimed to evaluate the intraoperative and postoperative outcomes of robot laparoendoscopic single-site surgery performed with the da Vinci Xi system.

Materials and Methods: Retrospective chart review of patients undergoing of robot laparoendoscopic single-site by a single surgeon using the Xi single-site platform from November 2016 and May 2019. For the da Vinci Xi system, multichannel port and “Lap Single Vision” port access platform were placed through a single periumbilical incision.

Results: Fourteen patients underwent single-site surgery with benign cases (n=9) and partial nephrectomy cases (n=5). Among surgeries for the partial nephrectomy patients, one case of conversion to multiport robotic surgery occurred due to difficulty of tumor resection. Other major intraoperative complication, renal vein injury, was occurred in a patient who underwent a pyelolithotomy. The patient required a blood transfusion however, we were able to repair the vascular injury using prolene suture without additional port placement and open conversion. In our series, there were no conversions to open. The postoperative course was uneventful in all patients; only Clavien–Dindo III complications occurred.

Conclusions: Our preliminary experience with robot laparoendoscopic single-site surgery using the da Vinci Xi system demonstrated feasibility and safety in selected patients. Further studies with a greater number of patients in multiple settings will help to fully elucidate the role of da Vinci Xi surgical system in single-site surgery.

Keywords: Nephrectomy; Preliminary data; Robotic surgical procedures; Urinary tract

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INTRODUCTION

As the use of robot-assisted surgery continues to grow, more urology surgeons have adopted laparoendoscopic single-site (LESS) surgery to achieve a better cosmetic outcomes

than those with the multiport technique [1-3]. Komninos et al. [4] found that multiport robot-assisted partial nephrectomy achieved better trifecta outcomes (functional outcomes, patient safety and positive margins) than the robot laparoendoscopic single-site partial nephrectomy (R-LESS PN)

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approach (58.4% vs. 37.2%, respectively), demonstrating the limitations of a non-purpose-built robot platform for R-LESS. Nevertheless, the initial trial of the R-LESS PN technique was in its clinical beginning, and the benefit of this procedure were not clearly demonstrated. Therefore, purpose-built, single-site robot platforms were eventually developed to address these challenges [5].

In 2010, Intuitive Surgical Inc. (Sunnyvale, CA, USA) deal with the problem of instrument collision by developing the da Vinci single-site surgical platform. This platform uses a novel set of single-site instruments and accessories specifically designed to robot-assisted single-site surgery. With this instrumentation, extracorporeal robot arm clashing is minimized externally due to the curved cannulas that angle the robot arms further away from each other. Internal collision with the camera was avoided because the camera was designed to be placed in the center, between the left and right curved cannulas. The da Vinci single-site instruments are similar to those used for the multiport robot surgery with da Vinci Xi (Intuitive Surgical Inc.), except that the entire length of the da Vinci single-site surgical platform is semi-rigid, allowing them to be inserted into and flexed through the curved cannulas. Initially the R-LESS system didn't come with EndoWrist[®] technology, but they did eventually introduce EndoWrist[®] needle drivers. These technical advantages of the robot platform made R-LESS more feasible than the conventional laparoscopic platform. The fourth-generation robot da Vinci Xi surgical system demonstrated suitable instruments and a well-programmed robot platform for R-LESS. Significant progression of a curved cannula and flexible shaft instruments were attained in the field of R-LESS [5].

However, to date, no study has evaluated the da Vinci Xi surgical system for R-LESS in urology. Therefore, this report presents our preliminary clinical feasibility and safety of performing R-LESS for urologic conditions using the da

Vinci Xi surgical system.

MATERIALS AND METHODS

This study aimed to evaluate the intraoperative and postoperative outcomes, who underwent R-LESS procedures performed at Severance Hospital between November 2016 and May 2019. Data regarding patient demographics and perioperative outcomes were collected after obtaining approval from the Institutional Review Board of Yonsei University (approval number: 1-2018-0074). Written informed consent was obtained from all patients, after explanation of the novel surgical system was provided. A single surgeon with advanced skills and heavy experience in conventional laparoscopic and robot surgery, with W.K.H. total 14 cases, performed all procedures in this series. Patient demographics and perioperative outcomes were retrieved from the electronic medical records, retrospectively. Collected demographic data included age, body mass index (BMI), preoperative diagnosis, and procedure type. Intraoperatively, the performance time for each procedural step was recorded. Port entry time was defined as the time from umbilical incision to single-port placement. Robot docking time referred to the time needed to move the robot toward the operating table, fasten the robot arms to the inserted trocars, and place all robot instruments. Surgeon console time was defined as the total time that the surgeon was at console until completion of the procedure.

1. Surgical technique

The patient was placed a conventional lateral decubitus position with the ipsilateral side elevated. A vertical, midline incision, approximately 2.2 cm in length, was made at the umbilicus, and the multichannel port (Intuitive Surgical Inc.) was installed. The multichannel port was established by inserting one 8.5-mm endoscope trocar and two 5-mm

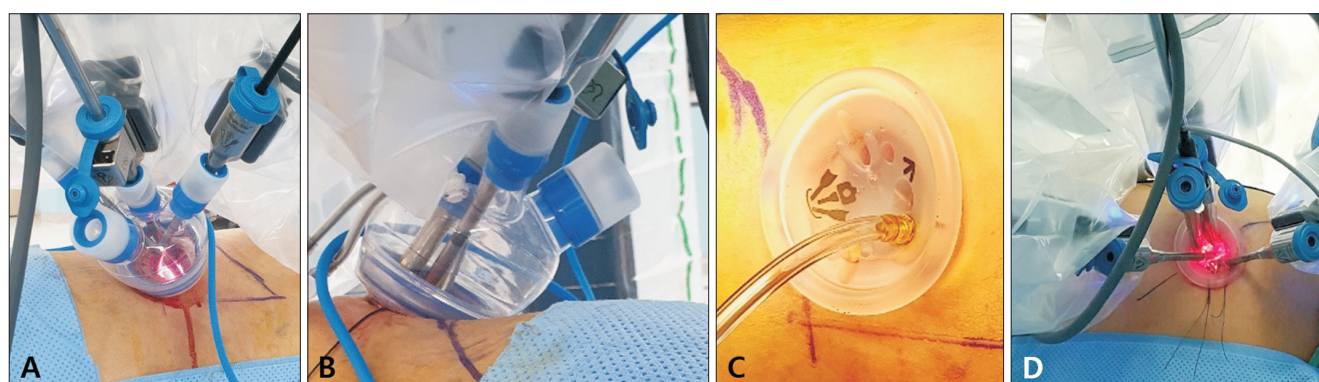


Fig. 1. (A, B) "Lap Single Vision" configuration for single-site robot surgery. (C, D) Multichannel ports configuration.

curved tunnels to specifically fit the crossing, curved cannula for robot instruments (Fig. 1). Instead of using the standard equipment multichannel port (Intuitive Surgical Inc.), which we found to restrict the number of instruments that can be functionally inserted simultaneously (Fig. 1C, D), we sometimes substituted this for a different advanced access platform, “Lap Single Vision” system (Sejong Medical, Paju, Korea). This modified system, similar to the more familiar Alexis wound retractor (Applied Medical, Rancho Santa Margarita, CA, USA), possesses greater elastic properties, thus enabling functional use of four simultaneous channels (Fig. 1A, B). This setup allowed for much greater versatility than the standard setup, thereby allowing devices of various sizes, ranging from 3 to 15 mm, to be used. In cases which the standard, multichannel port was used, the camera was inserted through the 8.5-mm port, the robot arms were installed through the two 5-mm curved cannula, and the 5 or 10-mm straight port was used for as an assistant port. The fourth robot arm was not used in all patients. For right-sided cases, an additional 5-mm port was inserted in the subxiphoid area for liver retraction. The robot was docked in the dorsal side and perpendicular direction on the patient’s table. All surgeries in the present study were finished with the da Vinci Xi surgical system.

After the robot was docked, the bowel was mobilized to the iliac area, and the descending colon was swept medially using blunt dissection to expose the gonadal vessels and ureter. Then, the ureter was dissected medially to the region of the iliac vessel. Cephalocaudal dissection was performed around the kidney until its posterior space was reached. The kidney was elevated until the renal hilum was visible, and the renal vein and artery were exposed to prepare for clamping.

The pyeloplasty surgery involved reproducing the steps of our own multiport robot-assisted pyeloplasty. An incision was made along the white line of Toldt, and the colon was mobilized medially to expose Gerota’s fascia; an incision was made in Gerota’s fascia to isolate the renal pelvis and ureter. Pyeloplasty was performed using the Anderson–Hynes technique. After excision of the obstructed ureteropelvic junction, the ureter was longitudinally spatulated. The anastomosis was performed on the posterior side with a running 4-0 absorbable, sterile suture. Ureterolithotomy, pyelolithotomy and simple nephrectomy were also performed in a similar manner (Fig. 2A, B).

For partial nephrectomy to resect renal tumors, intraoperative ultrasound with TilePro™ (Intuitive Surgical Inc.) projection onto the console screen was used to confirm

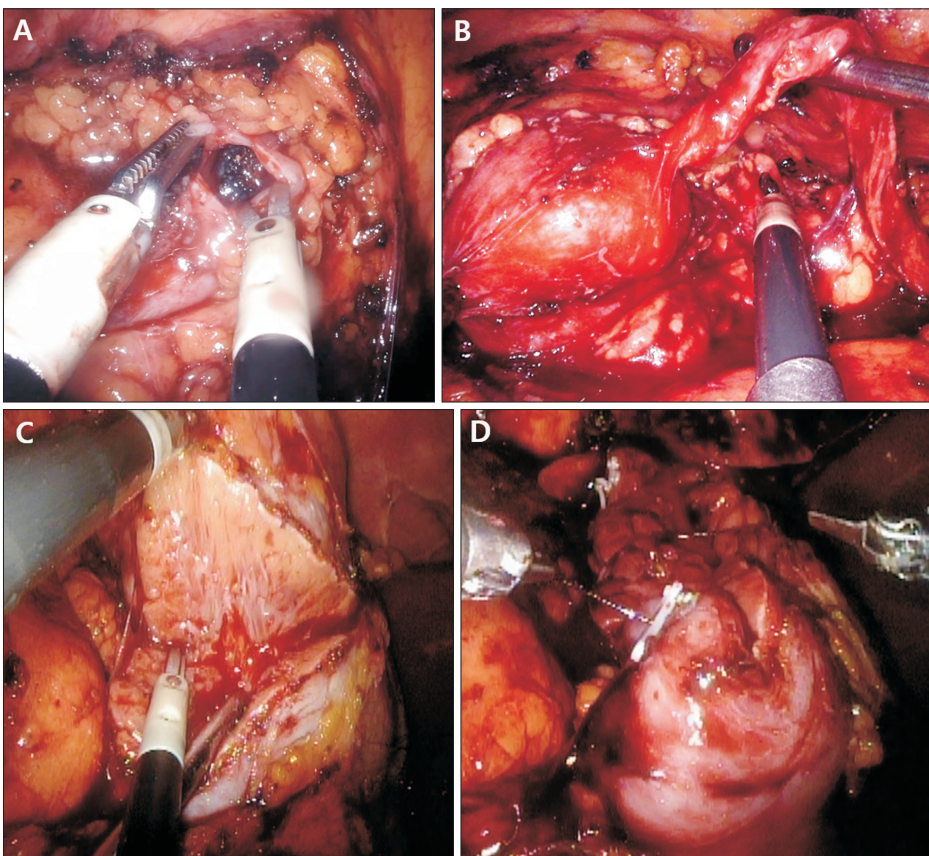


Fig. 2. (A) Incision into renal pelvis in robot-assisted laparoendoscopic single-site pyelolithotomy. (B) Dissection of ureteropelvic junction obstruction lesion in robot-assisted laparoendoscopic single-site pyeloplasty. (C) Tumor resected along the previously scored margin using cold scissors in robot-assisted laparoendoscopic single-site partial nephrectomy. (D) Renorrhaphy performed in two layers using robot needle drivers in robot-assisted laparoendoscopic single-site partial nephrectomy.

the margins of the mass. Temporary occlusion of the renal artery and vein was achieved using laparoscopic bulldog clamps (Aesculap, Tuttlingen, Germany) placed by an assistant. The tumor was excised using the non-wristed curved scissors (Intuitive Surgical Inc.) (Fig. 2C). Renorrhaphy was performed using a running, barbed monofilament suture (V-LOC™; Covidien, Dublin, Ireland) (Fig. 2D), with permanent, locking plastic clips (Hem-O-Lock; Teleflex, Research Triangle Park, NC, USA) (Fig. 2D), using a technique adapted from by Benway et al. [6].

RESULTS

From November 2016 and May 2019, 14 patients underwent R-LESS for benign and malignant urologic conditions. Four patients underwent ureterolithotomy, one who also underwent concomitant renal cyst marsupialization. Two patients underwent pyelolithotomy. Two patients underwent pyeloplasty for ureteropelvic junction obstruction, one who also underwent pyelolithotomy. In one patient, simple nephrectomy was performed for non-function kidney. Partial nephrectomy was performed in five patients for renal cell carcinoma. Patient demographic characteristics and indications for surgery are summarized in Table 1. The median patient age was 55.8 years (range, 30–85), the median BMI was 23.2 kg/m² (range, 19.1–32.0 kg/m²). The mean docking time was 14.0 minutes (range, 8.0–24.0 minutes), and the mean console time was 110.9 minutes (range, 30.0–177.0 minutes) for all surgery. In one pyelolithotomy patient who had undergone pyeloplasty with ureteropelvic junction obstruction 10 years ago, massive bleeding occurred due to injury of the renal vein during surgery. The patient required a blood transfusion. However, we were able to repair the vascular injury using prolene suture. A double-J stent was not inserted postoperatively, and unfortunately the patient underwent a percutaneous drainage on postoperative day 7 after developing a postoperative urinoma. A percutaneous drain was removed after retrograde double-J stent insertion at postoperative day 14, and the patient was discharged at postoperative day 20.

The demographic characteristics of the five patients with renal tumors are summarized in Tables 2 and 3. All the procedures were completed by clamping the renal vessels. Additional ports were used in one case. The mean operative time was 193.0 minutes (168.0–229.0 minutes), and console time was 129.80 minutes (88.0–177.0 minutes). The mean warm ischemic time was 31.0 minutes (23.0–47.0 minutes). Estimated blood loss volume was 60.0 mL (0–100). None of the partial nephrectomy patients were transfused. No positive surgical margins were

Table 1. Baseline characteristics and perioperative data for patients who underwent robot-assisted laparoendoscopic single-site surgery for urological conditions

Characteristic	Value
Patient number	14
Type of surgery	
Ureterolithotomy	4
Pyelolithotomy	2
Pyeloplasty	2
Simple nephrectomy	1
Partial nephrectomy	5
Age (y)	55.8 (30–85)
Body mass index (kg/m ²)	23.2 (19.1–32.0)
Side (right/left)	7/7
Preoperative eGFR (mL/min/m ²)	97.5 (51.3–136.0)
Tumor mass size of the kidney (cm)	3.3 (2.0–5.4)
Surgical time (min)	155.8 (70.0–229.0)
Docking time (min)	14.0 (8.0–24.0)
Console time (min)	110.9 (30.0–177.0)
Blood loss (mL)	150.0 (0–1300.0)
Hospital stay (d)	5.9 (3–20)
Postoperative eGFR (mL/min/m ²)	101.3 (60.9–145.0)
Intraoperative complications	2
Postoperative complications (Clavien–Dindo >2)	1
Pain at discharge, NPIS score	2.3 (1–3)

Values are presented as number only or median (range).

eGFR, estimated glomerular filtration rate; NPIS, numerical pain intensity scale.

detected in any of the cases. One case (Patient 5) experienced antibiotics anaphylaxis, which resulted in prolonged induction time (a grade I complication according to the Clavien–Dindo classification system). One case (Patient 3) was changed to a multiport procedure due to the intraoperative difficulty of the tumor resection. Table 2 shows baseline characteristics of patients who underwent robot-assisted single-site partial nephrectomy, and Table 3 represents the perioperative and postoperative outcomes of these patients.

DISCUSSION

LESS, which is approaching trans-peritoneal cavity via a single 3 to 4 cm incision at umbilicus rather than multiple incisions, has received worldwide attention for reducing scarring and morbidity compared to conventional laparoscopic surgery. However, the wider adoption of this technique may be hindered by its limitations such as the lack of triangulation, difficulties with precise surgical movements, instrument collision and ergonomic discomfort. The progression of robot technology to LESS has overcome some of these limitations while maintaining the potential benefits

Table 2. Baseline characteristics of patients who underwent robot-assisted single-site partial nephrectomy

Characteristic	Case 1	Case 2	Case 3	Case 4	Case 5
Age (y)	45	52	54	65	45
Sex	Male	Male	Male	Female	Female
Body mass index (kg/m ²)	31.28	21.63	28.58	22.74	25.48
ASA score	1	1	2	2	2
Comorbidities	Hypertension	None	None	Hypertension	Antibiotics anaphylaxis
Previous surgery	Partial nephrectomy (right)	None	None	None	None
Laterality	Left	Right	Left	Right	Left
Tumor size (cm)	2.5	5.4	2	3	3.9
Location	Posterior medial	Lower	Lower	Lower	Lower
RENAL score	9	8	6	9	8
Pathology	Clear cell	Clear cell	Clear cell	Clear cell	Angiomyolipoma

ASA, American Society of Anesthesiologists; RENAL, radius, exophytic/endophytic, nearness to collecting system or sinus, anterior/posterior, location relative to polar lines.

Table 3. Perioperative and postoperative outcomes of patients who underwent robot-assisted single-site partial nephrectomy

Characteristic	Case 1	Case 2	Case 3	Case 4	Case 5
Operative time (min)	229	189	168	189	190
Console time (min)	177	133	88	137	114
Warm ischemic time (min)	23	33	24	47	28
Suture time (min)	18	31	10	8	14
Intraoperative complications	None	None	None	Difficulty of tumor excision	None
Conversion to other surgery	None	None	None	Insertion of additional port	None
Estimated blood loss (mL)	100	100	50	50	10
Discharge	POD 3	POD 6	POD 3	POD 4	POD 3
Clavien–Dindo complications	None	None	None	None	Grade I

POD, postoperative day.

of minimally invasive surgery through a single incision. The technical advancement of the robot platform makes LESS more feasible than the laparoscopic platform. However, the previous robot system and instruments were not originally designed for LESS. External collisions of the robot arms occur frequently, and the space for the bedside assistant is restricted by da Vinci Si surgical system [5]. The fourth-generation robot platform, the da Vinci Xi system, features several upgrades and modifications from the da Vinci S and Si systems [7]. Docking is made simpler due to a laser-guided, boom-mounted arm design. The new 8 mm, three-dimensional endoscope has been completely redesigned with an end-mounted digital chip camera that features an ability to mount on any robot arm (port hopping), an autofocus system and requires no draping. The robot arms feature an improved design with an additional joint, which allows for additional patient clearance and further improves the range of motion. The shorter docking time is attributed to the specially designed Xi robot arms, which allows for easier docking guided by a port placement menu and a laser auto-targeting system [8]. Kallungal et al. [9] described their operative

technique with the da Vinci Xi system in 15 patients who underwent multiport robotic partial nephrectomy (RPN). They found that multiport RPN with the da Vinci Xi system could be safely performed with acceptable pathological and perioperative outcomes. Overall, the surgeon felt that the da Vinci Xi system provided a significant improvement over the da Vinci Si system for robot partial nephrectomy [9]. Due to the technological changes to the robot, the port placement and docking procedure is quite different from the general procedure of the previous Si platform [5]. As the use of robot surgeries increase, more urologic surgeons have adopted LESS to achieve a better cosmetic outcome [1-3]. We performed R-LESS PN using the da Vinci Xi system for complex renal masses. In addition, benign urologic disease was successfully performed in single-site surgery. The primary advantage of this da Vinci Xi system was its ability to perform LESS more easily. Subjectively, we observed instrument stability, adequate ergonomics, a wide range of movements, and minimal clashing. The left robot instrument can be directed downward to the right, whereas the right one can be directed downward to the left. Although the robot

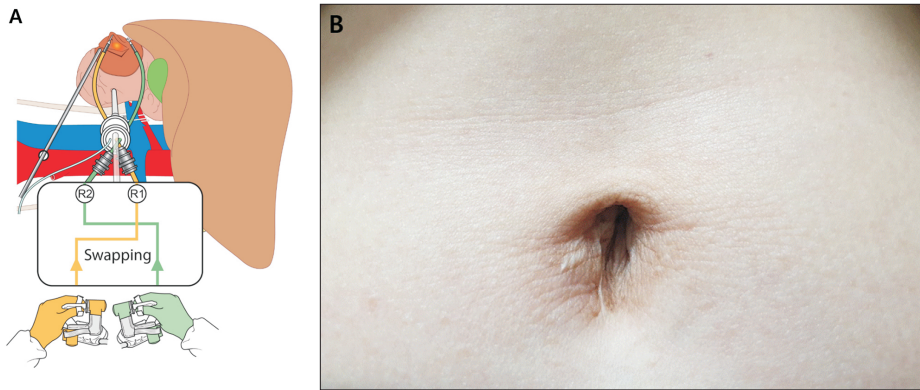


Fig. 3. (A) Scheme of the da Vinci single-site platform. (B) Postoperative overview after wound closure.

instruments cross at the entrance site, the instruments are automatically reassigned by the system software, so that the left hand of the surgeon's control directs the left instrument and vice versa. The development of this "chopstick" surgical device results in fewer collisions of the robot arms (Fig. 3A). Although the procedure was successful in these patients, some potential difficulties may result in performing robot LESS. The primary limitation of single site da Vinci Xi system is the lack of wrist articulation when operating with the fenestrated bipolar forceps, the permanent cautery hook, and the curved scissors. Furthermore, the use of an additional 5-mm subxiphoid liver retraction port for right-sided renal tumors with a 12-mm assist port is a deviation from the strict philosophy of LESS surgery; however, this seems to have become an accepted practice. The first multichannel port for single-site robot platforms could not handle an assistant port over 8 mm. Circumventing this limitation by placing an additional assistant 10 mm or 12 mm port meant R-LESS was not a 'pure' single-site surgery. However, using our modified multi-access port made by "Lap Single Vision" enabled us adhere to the concept of "pure" single-site surgery (Fig. 1A, B) in most cases. It is important to point out that even though we were able to accomplish these procedures, we encountered significant technical challenges during surgery. First, the lack of wristed technology on the instrument tips resulted in difficult tumor excision and renal resection-bed reconstruction; in one patient, the surgical approach had to be adjusted to add a conventional robot arm, in order to complete the case. The movement angle of single site wrist needle driver is 45 degrees. And the movement angle of multi-site wrist needle driver is 90 degrees. The difference of motion angle is relatively troublesome in doing renorrhaphy in R-LESS. Also, single platform is difficult to carry out renorrhaphy as robot arm has no wrist but needle driver. Second, the slight flexibility of the semi-rigid instrument shaft resulted in less-than-ideal tissue traction compared with the rigid multiport arm. Third, because the multichannel port is

harder than the glove port, it does not cause pneumoperitoneum loss due to tearing. However, in case of the assist insertion, the other port limits movement. In addition, instruments larger than 10 mm cannot be used in the standard multichannel port. The specially designed single-site silicone port helps to establish exact alignment of the flexible robotic instruments toward the target organ. However, skin injuries induced by the port has even been reported, due to pressure exerted by standard multichannel port [10]. When we modified our access system using the "Lap Single Vision" device, instead of the standard Intuitive robot multichannel port, we were able to successfully use an adequate assistant port with the robot instruments using a true single port access. We performed LESS using the da Vinci Xi system in the urological field for successful stone removal, tumor dissection, and pyeloplasty.

However, our study was limited by the small number of patients who underwent this specific surgery conducted by an experienced robot surgeon and including the patient selection bias, and the lack of a control group. Despite of these limitations, this is an initial study which describes our early R-LESS experiences with the da Vinci Xi platform and we will assessment of long-term oncological and functional outcomes in a larger group of patients is necessary in the future.

CONCLUSIONS

In conclusion, R-LESS is a feasible approach in the da Vinci Xi system which is many improvements over the previous version. LESS with the da Vinci Xi system could be a treatment option for select patients with urologic disease. A larger number of patients may benefit from the small incision using the da Vinci Xi system to facilitate R-LESS. Our initial report suggests that the da Vinci Xi Surgical System implement patient safety, because of major urologic procedures were successfully completed without open conversions, and mostly complications can control.

According to our initial experience, the use of R-LESS with the da Vinci Xi surgical system is safe and feasible to use for urologic procedures. We anticipate that our experience of da Vinci Xi system will help develop and renovate new robot system.

CONFLICTS OF INTEREST

The authors have nothing to disclose.

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AUTHORS' CONTRIBUTIONS

Research conception and design: Hyung Ho Lee and Woong Kyu Han. Data acquisition: Hyung Ho Lee, Joon Chae Na, and Woong Kyu Han. Statistical analysis: Hyung Ho Lee and Joon Chae Na. Data analysis and interpretation: Hyung Ho Lee and Young Eun Yoon. Drafting of the manuscript: Hyung Ho Lee and Woong Kyu Han. Critical revision of the manuscript: Hyung Ho Lee, Joon Chae Na, and Woong Kyu Han. Administrative, technical, or material support: Young Eun Yoon and Koon Ho Rha. Supervision: Koon Ho Rha and Woong Kyu Han. Approval of the final manuscript: Woong Kyu Han.

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