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Initial experience with the novel modular robotic system Carina in urology: a prospective study on safety feasibility and surgical settings

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Robot-assisted surgery has transformed urology, but widespread adoption remains limited by the high cost, complex setup, and rigid system design. This prospective single-center study evaluates the safety and efficacy of the novel modular Carina in 19 upper and lower urinary tract surgeries. All cases were completed robotically without conversion, with one major complication. For partial nephrectomy (PN), median operative time (OT) was 120 min with 50 mL estimated blood loss (EBL), including one off-clamp PN completed in 77 min (EBL: 50 mL). Pyeloplasty had a median OT of 105 min (EBL: 50 mL), while radical prostatectomy (RP) achieved a median OT of 150 min (EBL: 50 mL). Radical cystectomy was completed in 301 min without major complications, and an uncomplicated postoperative course. Median docking times were 5 and 8 min for upper and lower tract surgeries, with negative margins and preserved renal function in all PN, and social continence post-RP. The Carina system demonstrates procedural safety and feasibility in complex urological procedures. The modular design may enhance workflow and space utilization, suggesting the potential for promising tool and broader clinical applications. Further validation with larger sample sizes and long-term follow-up is needed.

Keywords Robot assisted surgery, Novel robotic system, Modular system, Carina™ platform, Surgical settings, Urologic procedures, Urology

Robotic-assisted surgery has significantly advanced minimally invasive procedures by enhancing precision and dexterity particularly in complex surgeries[1]. This advanced surgical technique has become beneficial in urology for complex procedures such as radical prostatectomies and partial nephrectomies[2]. However, conventional robotic systems are often limited by high costs, rigid designs, and restricted adaptability. Additionally, the steep learning curve for surgeons transitioning from laparoscopic techniques presents a challenge to broader adoption, especially in resource-limited settings where affordability is a significant concern[3,4].

Recent advancements in robotic surgery have led to the development of new systems designed to overcome the limitations of conventional platforms[5,6]. The Toumai system, recently CE-approved, incorporates advanced technologies such as force sensing, high-frequency response, and advanced imaging, with the capability for telerobotic surgery over a variety of network systems, including dedicated lines, 5G, fiber optic, and wired hospital networks[7]. The Hinotori robotic system offers unique features such as a semi-closed ergonomic console, a docking-free system, and a patient cart with four 8-axis operation arms[8]. A significant innovation in the field is the emergence of modular robotic systems, which provide greater flexibility and adaptability across surgical specialties. Modular systems like the Hugo RAS[9] and Senhance[10] provide customizable configurations that optimize space utilization and facilitate integration into diverse surgical settings. Designed to improve efficiency and reduce operational costs, these systems address limitations commonly associated with traditional robotic platforms.

The **Carina** robotic system, developed by Ronovo Surgical Ltd. (Shanghai, China), is modular platform featuring four mobile bedside modules, offering flexibility and adaptability to a wide range of surgical needs.

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This study evaluates the feasibility and safety of the **Carina** in upper and lower urinary tract surgeries, and describe the operative setup.

Materials and methods
Study design
This prospective study was conducted at the department of Urology, the First Affiliated Hospital of Zhengzhou University. All the participant were informed about the novel system, and a written informed consent was taken after the approval to undergo the surgery. Standardized preoperative and postoperative protocols were applied across all procedures. The study was approved by the institutional review board of the First Affiliated Hospital of Zhengzhou University (L2024-Q078-001), registered at the Chinese Clinical Trial Registry (www.chictr.org.cn; ChiCTR2400091115), on 21/10/2024, and conducted in compliance with the ethical guidelines of the Helsinki Declaration of 1975.

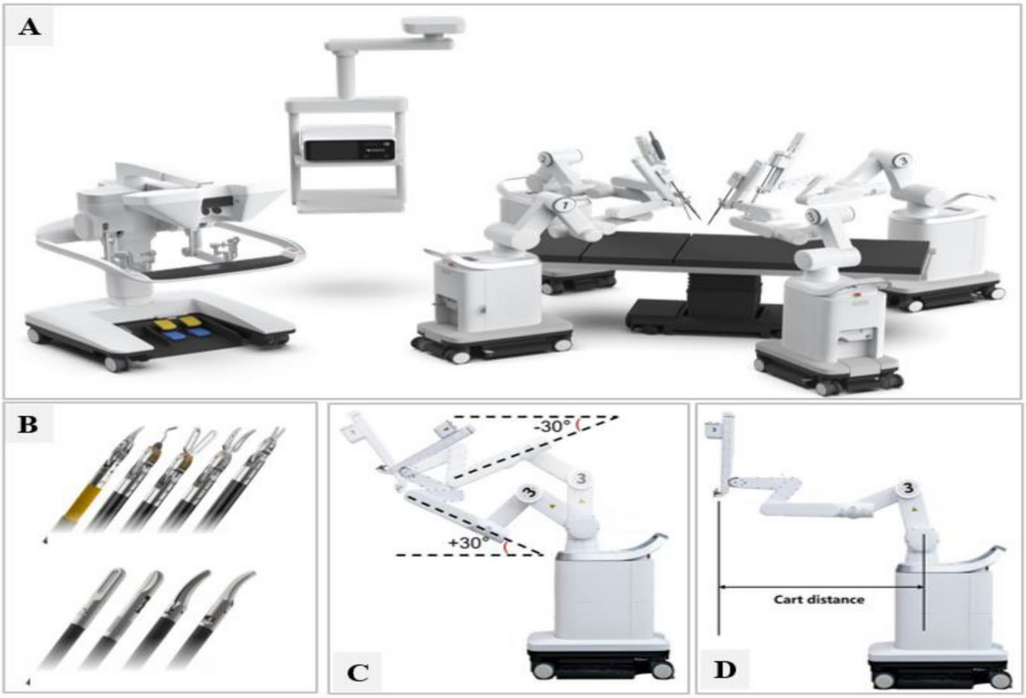
Study population
Consecutive patient undergoing various upper and lower urinary tract surgery were enrolled without specific selection criteria (Table 1). A total of 19 patients including partial nephrectomies (n = 10), pyeloplasty (n = 3), adrenalectomy (n = 1), radical prostatectomy (n = 4), radical cystectomy (n = 1) underwent surgery with the Carina Platform. All patients had undergone a standard preoperative evaluation prior to surgery. Exclusion criteria included refusal to provide informed consent, incomplete data, significant comorbidities contraindicating surgery, and metastatic disease.

The Carina platform
The **Carina** robotic surgical system is a master–slave platform consisting of a surgeon console, four independent patient carts, and an integration hub. Its "modular design" allows for flexible and independent configuration of key components, including the bedside cart, energy system, and endoscopic system. These components can be customized to meet the specific needs of different procedures (Fig. 1).

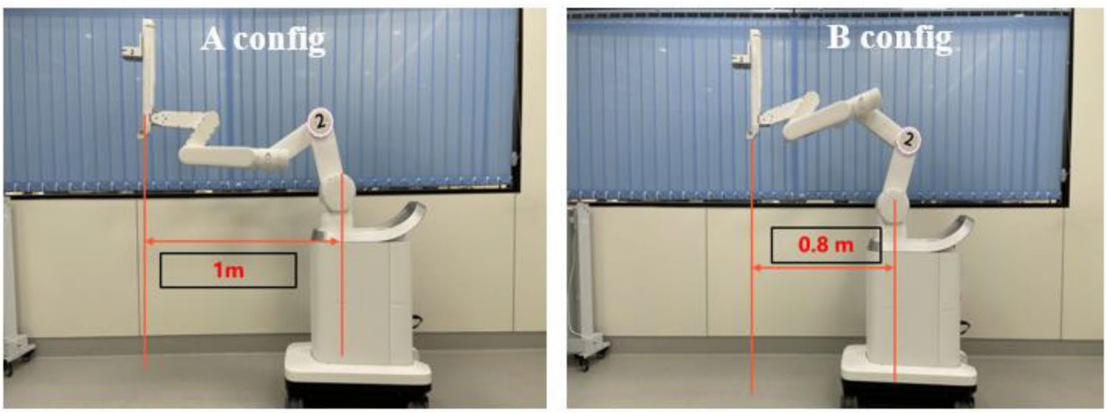
Surgeon console
The surgeon console features a closed stereoscopic viewing window for 3D visualization. Its interactive touchscreen display allows the surgeon to assign robotic arms to hand controllers and adjust console settings. The console includes two ergonomic hand controllers and foot pedals for optimized control. A key safety feature is the head-tracking sensor, which monitors the surgeon's visual focus on the 3D display. If the surgeon's head moves away from the display, the system automatically locks the robotic arms, enhancing patient safety. Additionally, the console incorporates a hand tremor filtering mechanism, improving precision and stability during complex procedures. To further ensure safety, both the console and patient carts are equipped with emergency stop buttons, allowing immediate intervention in case of system malfunction.

	Partial nephrectomy (n = 10)	**Radical prostatectomy (N = 4)**	**Pyeloplasty (N = 3)**	**Adrenalectomy (N = 1)**	**Radical cystectomy (N = 1)**
Basic characteristics					
Age	61.00 (44.81–67.41)	64.00 (48.89–77.11)	35.00 (8.49–51.51)	43.00	57.00
Gender	F/20%	F/50%	F/67%	F	M
BMI (kg/m^2)	24.50 (22.6–26.07)	25.75 (21.22–30.88)	21.9 (16.37–29.83)	21.50	29.40
Preoperative evaluation					
eGFR (ml/min)	93.62 (72.99–102.94)	–	115.90 (99.84–140.49)	82.31	96.3
Hb (g/L)	140.00 (132.54–149.02)	128.50 (114.19–141.81)	126.00 (99.07–143.60)	85.00	120.00
Cr (μmol/L)	–	72.50 (51.62–106.88)	58.00 (43.61–78.39)	51.00	75.00
PSA (ug/L)	–	5.76 (7.17–24.39)	–	–	–
Intraoperative recording					
Docking time (min)	6 (4.50–9.27)	8.50 (1.40–24.90)	4.00 (0.54–8.13)	4.00	7.00
Operating time (min)	120 (93.54–147.35)	150.00 (79.68–260.32)	105.00 (20.86–250.86)	145.00	301.00
EBL (ml)	50.00 (37.89–77.67)	50.00 (22.72–102.28)	50.00 (3.03–83.03)	400.00	300.00
WIT (min)	13.00 (8.36–16.53)	–	–	–	–
Postoperative evaluation					
eGFR (ml/min)	81.04 (63.99–92.59)		114.60 (78.52–139.68)	105.50	84.30
Hb (g/L)	134.00 (122.89–140.44)	124.50 (105.84–139.16)	126.00 (79.30–162.04)	88.00	135.00
Cr (μmol/L)	–	72.00 (53.61–98.39)	58.00 (9.56–130.44)	85.00	74.00
PSA		0.006 (0.002–0.013)			

Table 1. Demographic and operative parameters in 19 patients undergoing partial nephrectomy with Carina. Continuous variables are shown as medians (IQR). *BMI* body mass index, *eGFR* estimated glomerular filtration rate, *Hb* hemoglobin, *Cr* Creatinine, *PSA* Prostate Specific Antigen, *EBL* estimated blood loss, *WIT* warm ischemia time.



The Carina platform. (A) Surgeon console, patient cart, and integration hub. (B) Wristed and straight-stick instruments. (C) Example of operation space setting: -30°and +30°position. (D) Example of Cart distance



Display of different patient cart configuration and adjustable cart distance

Fig. 1. The Carina platform and patient cart configuration and display of different patient cart configuration and adjustable cart distance.

Patient cart

The system consists of four independent carts—one dedicated to the endoscope and three for the surgical instruments. Each cart can be positioned independently, offering enhanced flexibility during multi-quadrant surgeries, which is particularly advantageous in complex procedures requiring precise anatomical access. The system supports either a three- or four-cart configuration, depending on the specific procedural requirements. Its modular design allows surgeons to maintain standard laparoscopic settings, preserving familiarity with established techniques while integrating advanced robotic capabilities.

Each cart is equipped with a robotic arm featuring nine joints and seven degrees of freedom, providing an extensive range of motion for precise surgical maneuvers. Using the "Instrument Clutch," "Port Clutch," and “Operation Space” buttons, the robotic arms can be unfolded, extended, raised, or lowered, enabling seamless docking of instruments and the endoscope into the trocars. Instruments can be mounted on any of the instrument-holding carts, while the endoscope is positioned on the dedicated scope-holding cart, enhancing procedural versatility and adaptability. The space-efficient design of each cart optimizes operating room utilization, facilitating streamlined storage and easy mobility within surgical settings.

The integration hub
The integration hub serves as the central processing unit, connecting the endoscope, energy platform, monitor, and other essential equipment. It is compatible with standard 3D endoscopes from leading manufacturers such as Olympus and Karl Storz, ensuring easy integration with widely available surgical tools. Additionally, the system supports 3D endoscopes with fluorescence imaging capabilities currently under development by Ronovo Surgical. The hub enables full control of the robotic arms via the surgeon console and provides a two-dimensional monitor for the surgical team, displaying the endoscopic view, system notifications, and the real-time status of the arms and instruments. The system can also be utilized for conventional laparoscopic surgeries without the surgeon console, offering versatility in a range of surgical settings. The system supports both 8-mm wristed instruments and 5-mm straight instruments adapted from conventional laparoscopic instruments, allowing surgeons flexible choice of instruments.

Surgical procedures and patient cart configuration
All surgeries were performed by senior surgeon with extensive experience in over 4000 robotic surgeries. Partial nephrectomy[11], Pyeloplasty[12], radical prostatectomy[13] and adrenal surgery were performed through transperitoneal approach according to previously described technique.

Surgical setup
The first surgeon, bed assistants, and scrub nurses taking part in the operations had all completed the technical training on the **Carina** provided by Ronovo Surgical Ltd, (Shanghai, China). The recommended technical configurations for robotic urologic procedures, including patient positioning, port placement, and patient cart positioning, were based on the procedure cards provided by Ronovo Surgical (Fig. S1). These configurations were verified and optimized through extensive preclinical testing using porcine and cadaver models prior to this case series. Under general anesthesia, patients were positioned in either a Trendelenburg or a left or right flank position, depending on the specific requirements of the procedure. After achieving pneumoperitoneum with a Veress needle, a 10-mm trocar was inserted and a 30° camera was introduction to explore the abdominal cavity. Additional 8-mm robotic ports and 12-mm assistant ports were placed under direct visualization, maintaining a minimum of 8 cm between ports to prevent collisions between robotic arms.

Once all trocars were positioned, the robotic system was docked according to procedure-specific configurations. The system's modularity allows for adjustments in operational space settings and cart distances to optimize surgical field access and accommodate patient positioning. Before the docking process, all robotic arms are deployed into a draping configuration for easy installation of sterilized drapes. The patient carts are connected to the integrated hub and each arm is positioned using the "A" or "B" buttons to set the cart distance according to the procedure requirements. The patient cart is then moved to the designated location, aligned with the port site, and locked in place.

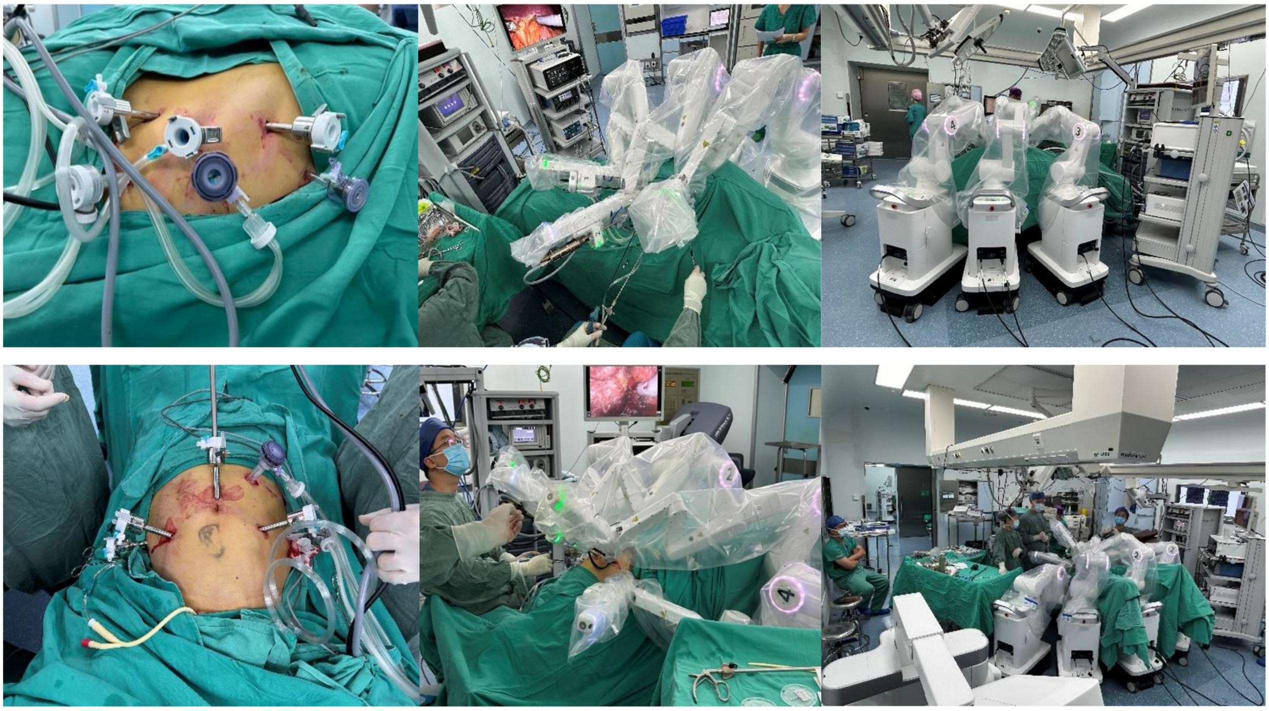
Once positioned, the robotic arms are docked to the trocars using the "Instrument Clutch," "Port Clutch," and "Operation Space" buttons. After docking, the arms are adjusted to the appropriate operational space. The 30° endoscope is attached to the camera arm, and instruments are connected to the respective arms: fenestrated bipolar forceps for grasping, monopolar curved scissors for dissection, a large needle driver for suturing, and, if necessary, a fenestrated forceps for exposure (Fig. 2).

Outcome measures
The primary outcome measures were the feasibility and safety of the novel robotic system during upper and lower tract surgeries. Feasibility was assessed based on successful completion of surgeries without the need for conversion to conventional techniques. Safety was evaluated by recording any intraoperative or postoperative complications. Secondary outcome measures included operative time, blood loss, length of hospital stay, and short-term functional and oncological outcomes. Complications were graded according to the Clavien–Dindo classification[14], with complications categorized as major (Grade ≥ 3) or minor (Grade ≤ 2).

Statistical analysis
Descriptive statistics were used to summarize the key variables of the study. Continuous variables, including operative time and surgical margins, were summarized using medians and inter quartile range to provide distribution and variability within the data. Categorical variables, such as patient demographics, complications, and other procedural outcomes, were reported as frequencies and percentages.

Results
A total of nineteen cases underwent various upper and lower tract procedures that consisted of ten partial nephrectomies, three pyeloplasty, one adrenalectomy, four radical prostatectomy, one radical cystectomy. The patient demographics and preoperative parameters are summarized in Table 1. All surgeries were successfully completed without conversions to alternative surgical approaches. Scheduled procedures were uneventful with no major intraoperative or machine-related complications.

*Upper tract surgery (*Table 1*)*
Patient characteristics
Ten partial nephrectomies were performed in eight male and two female patients, with six tumors located on the right kidney and four on the left. The median age of the patients was 61 years, with a median BMI of 24.50. The



Upper panel, trocar placement (left), intraoperative docking of robotic arm (middle) and individual patient cart configuration during partial nephrectomy (right); **lower panel**, trocar placement (left), docking of robotic arm (middle) and individual patient cart configuration during radical prostatectomy (right)

Fig. 2. Intraoperative setup, trocar placement, intraoperative docking of robotic arm and individual patient cart configuration during partial nephrectomy and radical prostatectomy.

RENAL scores ranged from 4 to 6, with the majority (7 cases) scoring 5 and three cases scoring 6. Additionally, three patients underwent left-sided pyeloplasty, two females and one male. One adrenalectomy was performed in a 43-year-old female with a large left-sided adrenal tumor extending to the renal pelvis.

Intraoperative and perioperative outcomes
The median docking time for partial nephrectomy was 6 min (4.50–9.27), with a median operative time of 120 min (93.54–147.35) and a blood loss of 50 mL (37.89–77.67). Ischemia time was a median of 13 min (8.36–16.53). One off-clamp partial nephrectomy was performed with a blood loss of 50 mL and an operative time of 77 min. In pyeloplasty, the median docking time was 4 min (0.54–8.13), with a median operative time of 105 min (20.86–250.86) and a blood loss of 50 mL (3.03–83.03). Adrenalectomy had a median docking time of 4 min, with an operative time of 145 min and blood loss of 400 mL.

Complications
No conversions to alternative surgical approaches were necessary. However, intraoperative bleeding during adrenalectomy was effectively controlled, though blood transfusion was required for stabilization.

Functional/oncological outcomes
Postoperative renal function following partial nephrectomies was satisfactory in all cases. All resection margins were negative, and no major complications were observed during the follow-up. For pyeloplasty and adrenalectomy, the patients showed stable postoperative progress with no major adverse event reported.

*Lower tract surgery (*Table 1*)*
Patient characteristics
Four radical prostatectomies were performed, with a median patient age of 64 years. The median PSA level was 5.77 µg/L (7.17–24.39), with Gleason scores of 3 + 4 (n = 1), 4 + 3 (n = 2), and 5 + 5 (n = 1). A radical cystectomy with ileal conduit was performed in a 57-year-old male patient.

Intraoperative and perioperative outcomes
For radical prostatectomy, the median docking time was 8.5 min (1.40–24.90), with a total operative time of 150 min (79.68–260.32) and blood loss of 50 mL (22.72–102.28). Limited lymph node dissection was performed in three patients, with a median of 15 nodes removed. Radical cystectomy with ileal conduit had a docking time of 7 min and a total operative time of 301 min, with an estimated blood loss of 300 mL.

Complications
For radical prostatectomy, surgical margins were negative in three patients, with no lymph node metastasis. One patient had a positive surgical margin (Gleason score 5 + 5). At the three-month follow-up, three patients were socially continent, and one required more than two pads per day. For radical cystectomy, there were no major complications.

Functional/oncological outcomes
At three months post-surgery, the majority of prostatectomy patients demonstrated satisfactory functional outcomes, with three patients achieving social continence. The radical cystectomy patient also had an uneventful recovery.

Summary of complications
A single major complication occurred, one patient developed a postoperative complication requiring percutaneous drainage under local anesthesia following pyeloplasty, categorized as Grade IIIa.

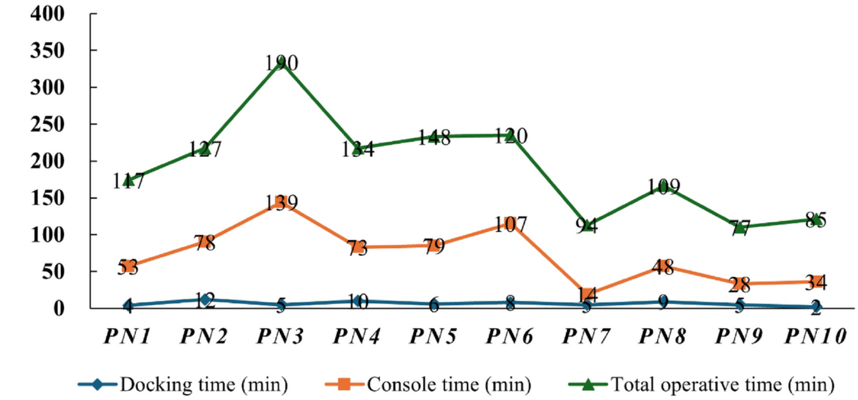
Discussion
This study presents an initial clinical trial evaluating the safety and feasibility of the **Carina** in urological surgeries. All procedures were successfully performed without conversions and major complications and no major machine-related malfunctions, suggesting the systems potential for use in diverse urological procedures.

The modular robotic platform demonstrated favorable clinical outcomes across 19 urological procedures, including both upper and lower urinary tract surgeries, with minimal complications. The operative times for partial nephrectomies (120 min) and radical prostatectomies (150 min) were comparable to established robotic systems[15]. Blood loss was minimal, with a median of 50 mL in both partial nephrectomies and radical prostatectomy, which aligns with or shows greater efficiency than conventional and emerging robotic systems, including the Hugo RAS and Versius systems[16,17]. The median docking times for pyeloplasty was 4 min, shorter than previously reported docking times for the Hugo RAS[18]. Additionally, the operative time and blood loss observed in these procedures were similar to those reported for both the Da Vinci and Versius systems[19,20]. These results highlight the potential of modular designs to achieve outcomes comparable to traditional robotic platforms, suggesting that the **Carina** may be a viable alternative for clinical applications[21].

The **Carina** features a modular design that supports three- or four-cart configurations, allowing customization based on procedural needs while maintaining familiarity with standard laparoscopic settings. It supports both 8-mm wristed instruments and 5-mm straight instruments, offering flexibility in instrument selection. Additionally, compatibility with standard 3D endoscopes from leading manufacturers, such as Olympus and Karl Storz, ensures seamless integration with widely available surgical tools. Safety features, including a surgeon console with a head-tracking system, enhance precision and control. Table 2 compares the major features of the **Carina** with the da Vinci and Hugo systems, highlighting its unique capabilities.

Features	DaVinci	Hugo RAS	Carina
Manufacturer	Intuitive surgical	Medtronic	Ronovo Surgical
Mode of robotic movement	Master–slave	Master–slave	Master–slave
Surgeon console	Closed	Open	Closed
3D viewing	Immersive viewfinder	Passive 3D glasses	Immersive viewfinder
Surgeon control	Finger grip, foot pedals	Pistol-like handle, foot pedals	Finger grip, foot pedals
Patient cart	4 robotic arms mounted in a single patient cart	3–4 independent modular arms	3–4 independent modular arms
Optics	8 mm, 3D, HD	10 mm, 3D, HD	10 mm, 3D, HD
Compatible with third-party laparoscopic platforms	No	Yes	Yes
Compatible with third-party energy platforms	No	Yes	Yes
Instrument, diameter	Wristed, 8 mm	Wristed, 8 mm	Wristed, 8 mm; Straight-stick, 5 mm
Instruments' reusability	Reusables, 10 times	Reusables, 15 times	Disposables (8 mm); Reusables (5 mm), 20 times
Ergonomic settings	Yes	Yes	Yes
Scale motion	Yes	Yes	Yes
Force feedback	Yes	No	No
Safety feature	Console with head tracking system	3D glasses with head tracking system	Console with head tracking system
Location of emergency stop button	Console	Console and Cart	Console and Cart
Docking memory	Yes, procedure specific	Not available	Yes[a]
Role of bed-side assistant	Supporting, passive	Supporting, passive	Supporting, passive
Camera	0° and 30°, 10 mm, no ICG	0° and 30°, 8 mm, ICG	0° and 30°, 10 mm, ICG[a]

Table 2. Comparison of the major features of the, da Vinci, Hugo and Carina robotic surgical platforms. *3D* Three Dimension, *HD* High-Definition, *ICG* Indocyanine Green. [a]Under development.



Trends in operative, docking, and console times for 10 consecutive partial nephrectomies (PN) demonstrating decreasing operative, console times and consistent docking efficiency.

Fig. 3. Trends in operative, docking, and console times for 10 consecutive partial nephrectomies demonstrating decreasing operative, console times and consistent docking efficiency.

Several features of the **Carina** may provide potential benefits, particularly in resource-limited environments. Its reusable instruments, compatibility with standard 3D endoscopes, and configurable cart setups provide flexibility, potentially supporting institutions with limited budgets or space availability. The four-minute docking times observed in pyeloplasty and adrenalectomy procedures are notably efficient and represent a promising outcome, likely due to optimized space utilization and enhanced instrument coordination, potentially improving workflows efficiency. The ability to perform off-clamp partial nephrectomy with minimal blood loss also demonstrates the system's precision in preserving renal function, a key advantage commonly associated with conventional robotic systems[22]. However, these observations should be interpreted with caution, the absence of direct comparison and surgery performed by single high-volume surgeon limit the generalizability of the results, particularly for less experienced teams. The single positive surgical margin observed in a high-grade prostatectomy is consistent with outcomes seen in established robotic platforms[23], underscoring that technical success depends on tumor characteristics and surgical expertise.

The high cost of current robotic systems is a major barrier to their widespread adoption. The **Carina** offers potential cost-saving benefits through reusable instruments (up to 20 cycles), compatibility with third-party energy and laparoscopic platforms, and non-proprietary 3D endoscopes, reducing the need for additional equipment purchases. Its modular design requires minimal operating room space (≥ 35 m^2), making it suitable for smaller surgical rooms and avoiding costly renovations. These features, alongside customizable cart setups, suggest that the **Carina** may offer a more affordable alternative to traditional robotic platforms. While a formal cost-effectiveness analysis was not conducted, these advantages indicate its potential to improve accessibility, particularly in regions where the high initial cost of systems like the da Vinci limits adoption[24].

The **Carina** compatibility with conventional laparoscopic tools facilitate the transition for laparoscopically trained surgeons to robotic surgery, reducing the adaptation period[25]. Its control interface, similar to the Da Vinci robot, provides a familiar user experience for experienced users, reducing the need for extensive training. Additionally, the platform's modular components support incremental skill acquisition, allowing surgeons to master tasks progressively. The improvement in docking times observed in this series as surgical teams gained experience (Fig. 3) further suggests that modularity may help shorten the learning curve[26]. These features highlight the potential for a more efficient transition, although formal studies are needed to provide more robust evidence. However, complex procedures, such as partial nephrectomy and radical cystectomies, remain challenging and may be attributed to factors such as the learning curve associated with using the novel **Carina**, the complexity of procedures, and the multi-module design requiring manual positioning of the independent arm carts[27].

This study demonstrates the feasibility and safety of the **Carina**, particularly its modular design, in performing major urological surgeries across both upper and lower urinary tracts. The system's flexibility, versatility, and portability address the operational limitations often associated with conventional robotic systems. These innovations highlight the potential of modular robotic platforms to improve healthcare quality, accessibility, and efficiency, while offering a more cost-effective alternative to traditional robotic systems[28].

The study has several limitations that should be considered. First, it was conducted at a single institution with a relatively small sample size, which limits the generalizability of the findings. Additionally, the surgeries were performed by a highly experienced surgeon with over 4000 robot-assisted surgeries, which may not reflect the outcomes achievable by surgeons with less experience. Second, the short-term follow-up period may not capture the full range of potential long-term outcomes or complications associated with the **Carina**. Finally, while the study highlights initial feasibility and safety, formal studies assessing the impact of the system on the learning curve, workflow efficiency, and cost-effectiveness are essential to provide more robust evidence of its clinical applicability across different settings and surgical teams.

Conclusion

The preliminary study on the **Carina** demonstrates its feasibility and safety in performing diverse urological procedures. The platform's modular architecture and compatibility with conventional instruments may address cost and adaptability barriers associated to current robotic systems, potentially improving accessibility to minimally invasive techniques. However, longer-term studies with larger sample sizes are needed to validate these encouraging initial outcomes, assess the system's broader clinical applicability and cost-effectiveness.

Data availability

The datasets used and/ or analyzed during the current study available from corresponding author on reasonable request.

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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