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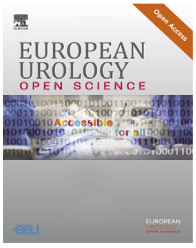

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Surgery in Motion: Open Science

Robot-assisted Single-port Radical Prostatectomy with the SHURUI SP and da Vinci SP Platforms: Comparison of the Technology, Intraoperative Performance, and Outcomes

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Abstract

Background and objective: The purpose-built SHURUI single-port (SP) robotic platform has recently been introduced for several procedures in urology, general surgery, and gynecology. However, comparative evidence on its performance in relation to earlier models such as the da Vinci SP is lacking. Our aim was to compare the step-by-step techniques and 1-yr outcomes for radical prostatectomy (RP) between the SHURUI SP and da Vinci SP robots.

Methods: Data were retrieved from two prospectively maintained databases. The SHURUI SP robot was used to perform RP in 34 patients in China (September 2021 to August 2022); the da Vinci SP robot was used to perform 100 consecutive RP cases in the USA (June 2019 to October 2020). A comparative analysis was conducted before and after 1:1 propensity score matching for age, body mass index, American Urological Association symptom score, prostate size, prostate-specific antigen (PSA) levels, biopsy grade group, and D'Amico risk group. Intraoperative performance and short-term oncological and continence outcomes were compared

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between the groups. Biochemical recurrence was defined as two consecutive postoperative PSA levels >0.2 ng/ml. Continence was defined as full recovery of urinary control without the use of pads. The Kaplan-Meier method was used to estimate continence recovery curves, and a log-rank test for trend was used to detect ordered differences in continence recovery between the SHURUI SP and da Vinci SP groups after surgery.

Key findings and limitations: For the matched SHURUI and da Vinci groups, median age (69 vs 69 yr), median PSA (8.4 vs 7.1 ng/ml), and the proportion of patients with low-risk (33.3% vs 29.6%), intermediate-risk (66.7% vs 63%), and high-risk disease (0% vs 7.4%) were comparable (all $p > 0.05$). All surgeries were successfully accomplished without conversion. A higher percentage of cases in the SHURUI group involved extraperitoneal access (81.5% vs 0%; $p < 0.001$) and a pure SP approach (25.9% vs 0%; $p = 0.01$), while a higher percentage of cases in the da Vinci group had nerve-sparing surgery. The median total operative (215 vs 110 min; $p < 0.001$) and median console time (162 vs 75 min; $p < 0.001$) were significantly longer in the SHURUI group. No intraoperative or major postoperative complications were observed in either group. Rates of positive surgical margins (18.5% vs 14.8%; $p = 1.0$) and extraprostatic extension (14.8% vs 29.6%; $p = 0.19$) were similar. At median follow-up of 13.5 versus 15.9 mo, none of the patients had experienced biochemical recurrence. At 1 yr after surgery, the continence rate was 96.3% in both groups.

Conclusions: Despite differences in driving mechanisms between the two SP robotic systems, RP can be performed safely and effectively with the SHURUI RP robot during the initial learning phase, with similar short-term oncological and continence outcomes to those with the da Vinci SP robot.

Patient summary: We compared two surgical robots (SHURUI SP and da Vinci SP) used to perform robotic surgery to remove the prostate through a single keyhole incision instead of multiple incisions. Our results show comparable technology and similar surgical and short-term cancer control outcomes for the two robots.

1. Introduction

Clinical use of the purpose-built da Vinci single-port (SP) robotic platform has led to renewed interest in robotic laparoendoscopic single-site surgery, and several urological procedures have been successfully completed with the da Vinci SP999 [1] and SP1098 [2] models, and the current commercially available SP system [3–11]. The system is designed to emulate the functionality of a multiport robot via insertion of several double-jointed, articulating robotic instruments through a multichannel SP. These instruments are capable of surgical triangulation at the operative site, similar to that achieved in multiport procedures, thereby facilitating complex surgical maneuvers. However, the wire-driven mechanism of the da Vinci SP instruments is prone to mechanical deformation, which negatively affects force transmission and workspace volume. The SHURUI SP platform was developed using a dual-continuum mechanism and core nitinol arm technology (Nitin Arm) [12,13]. The structure comprises a proximal structure, a set of guiding cannulae, and distal segments. The proximal structure actuates 20 hyperelastic nickle-titanium rods that comprise flexible surgical instruments that bend as a whole. Only a few studies tested this hypothesis using the first-generation format in small patient series of patients, mainly focusing on the feasibility and safety of performing surgeries with the SHURUI SP system in urology [14–16], general surgery [17], and gynecology [18]. However, the performance in comparison to earlier SP robotic models such as the da Vinci SP [2,19] is largely unknown. As we expect increasing adoption of this commercially available new technology, it is important to provide comparative evidence regarding the different robot systems for patients, surgeons, and health care stakeholders.

Radical prostatectomy (RP) is one of the most common procedures performed via different surgical approaches with the da Vinci SP platform [20,21]. In comparison to multiport surgery, the SP approach may offer satisfactory intraoperative performance and short-term postoperative outcomes even during the surgeon's initial learning phase [22,23] despite the lower traction and tissue-gripping capacity [23–25]. As the SHURUI SP robot is a recent introduction, albeit with increasing interest worldwide, no centers have comparative data on surgical outcomes for these two purpose-built SP robots. Hence, our aim was to compare the technological features and intraoperative and short-term postoperative outcomes for the SHURUI SP and da Vinci SP robots using data from an international collaboration of referral centers for patients undergoing robot-assisted RP (RARP).

2. Patients and methods

This study included data from four high-volume referral robotic centers (three in China and one in the USA). Institutional review board approval or exemption was obtained at each center. Data on RARP procedures performed by three experienced surgeons in China (L.W., Q.Z., and D.X.) using the SHURUI SP platform between September 2021 and August 2022 were retrieved from a prospectively maintained database (registered at www.chictr.org.cn, ChiCTR2100048179). These data were compared to a single-surgeon (V.P.) case series of consecutive patients who underwent RARP using the da Vinci SP between June 2019 and October 2020 at a referral center in the USA. The inclusion criteria for patients eligible for RARP performed with an SP robotic approach using these two platforms are presented in Supplementary Table 1.

De-identified information was provided by each center and compiled within an encrypted dataset by a single investigator (Z. Wang) who was blinded to the study design. A retrospective analysis was performed to compare outcomes achieved with the two SP robots before and after propensity score matching.

2.1. Study endpoints

The primary endpoint of the study was comparison of the SHURUI SP and da Vinci SP robotic platforms in terms of technology, intraoperative performance, and surgical complications. Postoperative complications were reported according to the modified Clavien-Dindo classification [26]. Secondary endpoints were 1-yr oncological and continence outcomes, specifically the rate of biochemical recurrence, defined as prostate-specific antigen (PSA) $\geq$0.2 ng/ml in two laboratory tests, and the proportion of patients with full urine control without the use of any pads after surgery.

2.2. SHURUI SP and da Vinci SP robots

The SHURUI SP robot, approved for clinical use in China by the National Medical Products Administration in July 2023, is a purpose-built platform. Unlike the cable-driven da Vinci SP instruments with joints and rigid links, dozens of superelastic nitinol rods, referred to as backbones, are redundantly arranged along the distal and proximal ends of the Nitin Arm instruments, providing continuous deformation with large bending angles and high payload capability and reliability (Fig. 1). The robot consists of a surgeon console and a patient

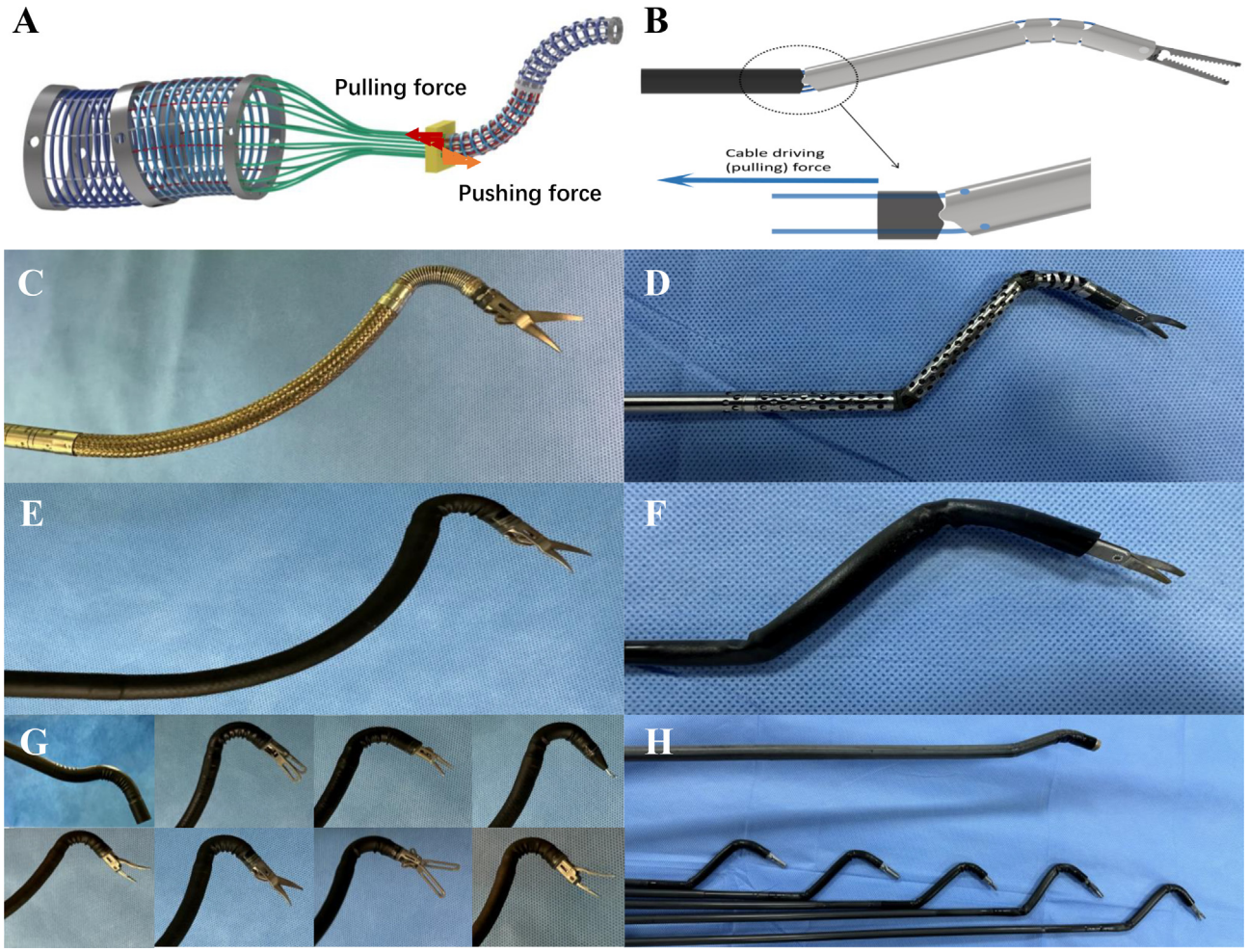

Fig. 1 – Characteristics of the SHURUI SP and da Vinci SP robotic systems. (A) Design principle featuring a dual continuum mechanism and a structure composed of dozens of superelastic nitinol rods for continuous deformation of the SHURUI SP instruments. (B) Wire- and link-driven mechanism with rigid joints of the da Vinci SP instruments. (C, E) View showing the continuous deformation of the SHURUI SP instruments. (D, F) View showing the multijoint articulation of the da Vinci SP instruments. (G, H) Comprehensive view of instruments for the two SP robotic systems.

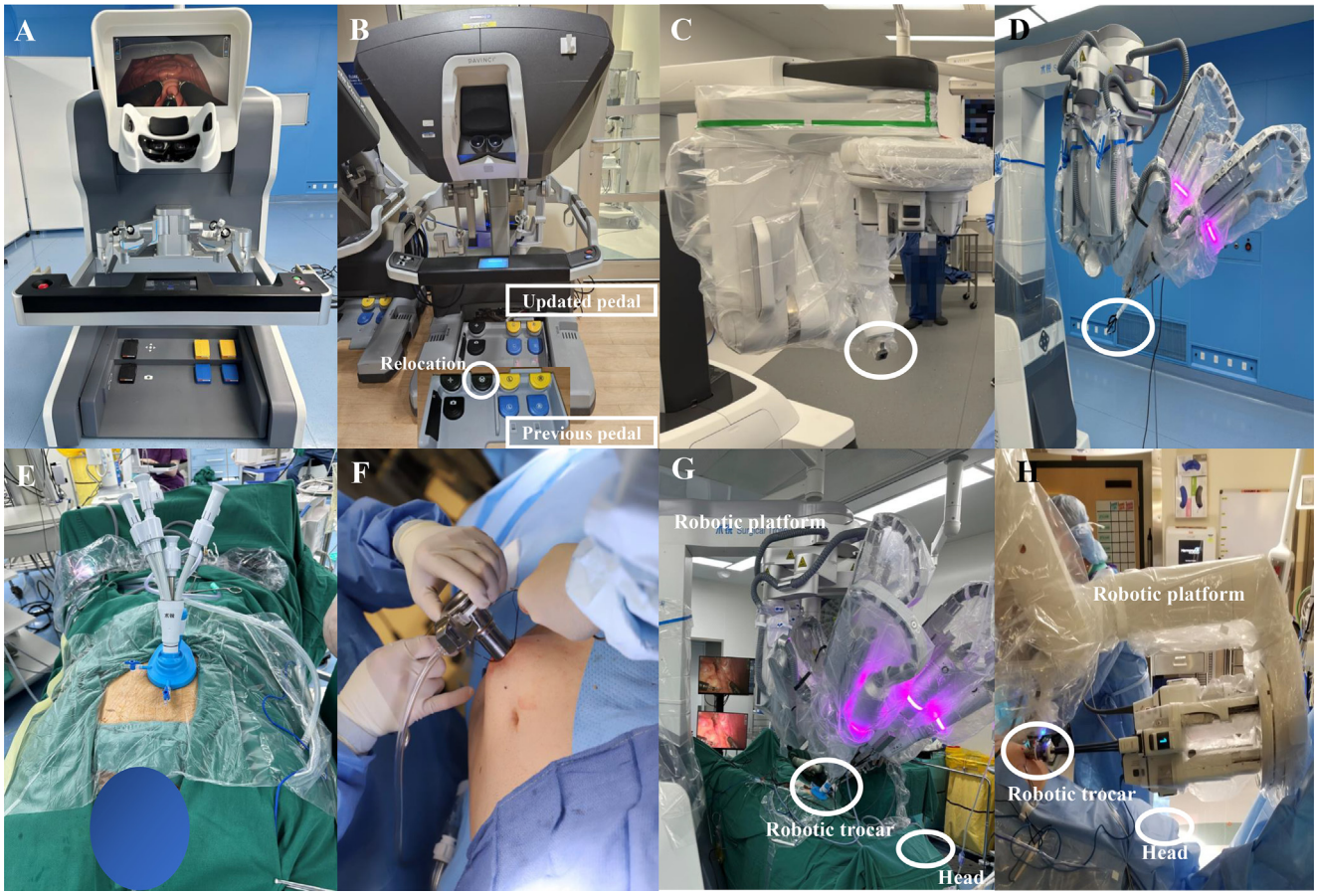

Fig. 2 – Comparison of the SHURUI SP and da Vinci SP robotic systems: (A, B) surgeon consoles, (C, D) patient carts, (E, F) port placement, and (G, H) final aspect after docking and insertion of the instruments.

cart (with vision system integrated) (Fig. 2). All four independent arms (three different working instruments with a diameter of 8 mm and a scope with a diameter of 10 mm) can be housed in a single multichannel port (25-mm-diameter trocar; Fig. 3). The innovative dual-continuum drive mechanism and Nitin Arm technology mean that the two bending segments of each instrument can be continuously deformed to obtain an adequate workspace and good transmission of force (Fig. 4). The technology for the da Vinci SP platform has been described in detail previously [19]. The technological characteristics of the robots are detailed in Table 1.

2.3. SP robotic RP technique

To maintain the surgical principles in RARP, an additional port was electively used during initial implementation of both the SHURUI SP and da Vinci SP robots (Fig. 2). The step-by-step RARP procedure with each robot has previously been described in detail [14,16,19,23]. In this study, we compared the intraoperative performance of the two robots for crucial steps in the surgery (Supplementary video).

2.3.1. Anesthesia, patient positioning, and port placement

All patients underwent surgery under general anesthesia and a bilateral transversus abdominis plane block without any other local analgesia [27]. In the da Vinci SP group, a transperitoneal anterior approach was used in all cases with patients placed in a dorsal decubitus 26° Trendelenburg position. One robotic trocar was placed above the umbilicus, and one additional 12 mm trocar was placed in the right lower quadrant. In the SHURUI® SP group, a 3-cm incision around the umbilicus (transperitoneal approach) or 3 to 4 cm below the umbilicus (extraperitoneal approach) was made for multichannel port insertion, with or without placing one additional 12 mm trocar in the right lower quadrant, with the patients placed in a similar position. Sided docking was used for both robots, with the scope placed at the 12-o'clock position (Fig. 2).

2.3.2. Dropping of the bladder and anterior dissection of the bladder neck

When using the da Vinci SP robot, the instruments were placed in the following order: scissors at the 3-o'clock, bipolar forceps at the 6-o'clock, and Cadiere forceps at the 9-o'clock position as a fourth arm for grasping tissue. For the SHURUI SP robot, the procedure was started with the scissors at the 3-o'clock and bipolar forceps at the 9-o'clock position for dissection, and a tissue grasper at the 6-o'clock position for traction. The anterior bladder neck was then accessed (Fig. 5). During this step, the relocation pedal was used frequently to target the robot to different sites for the da Vinci SP, but not for the SHURUI SP robot.

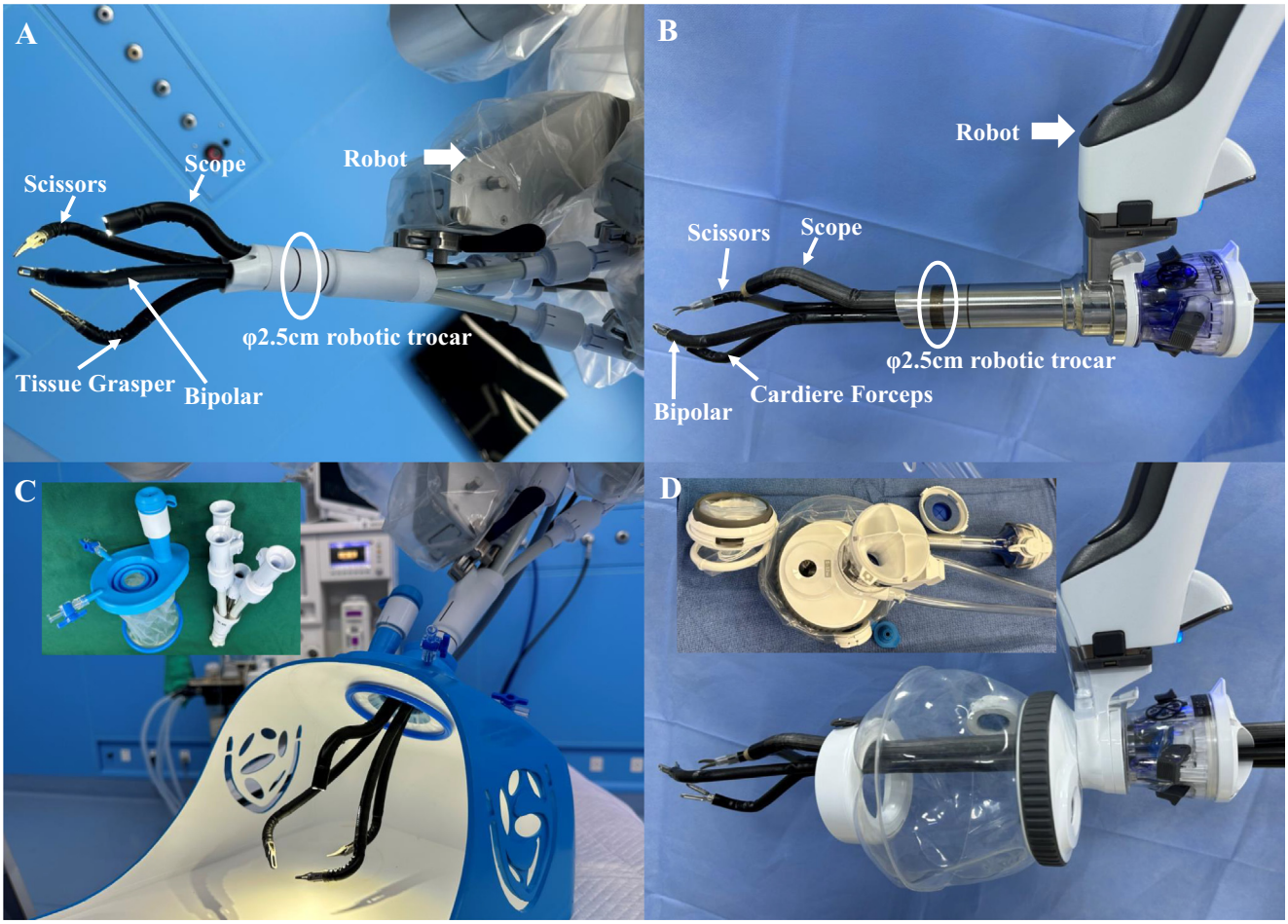

Fig. 3 – Instrument configuration for the SHURUI SP and da Vinci SP robotic systems. (A, C) The four arms converge to a single 2.5-cm-diameter robotic multichannel cannula with a combinable incision protector for the SHURUI SP robot. (B D) Similar instrument configuration of the SHURUI SP robot to the two currently available da Vinci SP robotic trocars.

2.3.3. *Posterior dissection of the bladder neck and seminal vesicles*

With the scope deflected with downward angulation facing the prostate, the anterior bladder neck was opened and the Foley catheter was then lifted with traction towards the pubic bone using the Cadiere forceps placed at the 9-o'clock position with the da Vinci SP robot and the tissue grasper at the 12-o'clock position with the SHURUI SP robot. Posterior dissection of bladder neck was performed up to the plane of the seminal vesicles. Under the same instrument configuration for both robots, the seminal vesicles were dissected and lifted with the da Vinci Cadiere forceps or the SHURUI tissue grasper applying traction towards the abdominal wall.

2.3.4. *Posterior dissection of the prostate and nerve sparing*

Denonvilliers fascia was released with the scope deflected in upward angulation (rotating the integrated arm to place the scope at the 6-o'clock position with the da Vinci SP robot and using the inverted cobra mode with the SHURUI SP robot to relocate the scope to the 6-o'clock position). In cases with an indication to spare the neurovascular bundles and the prostatic fascia, this was performed in a similar way with the two robots. During this step, deflection was crucial to visualize the posterior dissection plane.

2.3.5. *Apical dissection and anastomosis*

The approach for this step was similar with both robots. During apical dissection, the prostate was under downward traction (away from the pubis) with the da Vinci Cadiere forceps or the SHURUI tissue grasper placed at the 6-o'clock position and the scope was straight at 0° or angled slightly upwards. The urethra was then divided while preserving the maximum amount of urethral length and apical tissue. Vesicourethral anastomosis was performed with a running bidirectional barbed suture.

2.3.6. *Lymph node dissection*

During pelvic lymph node dissection, the robot was targeted to the operative site (on both sides) using the relocation mode (hand control, and previously pedal control, with the da Vinci SP and button control on the patient cart with the SHURUI SP).

2.4. *Statistical analysis*

Patients who underwent RARP performed with the SHURUI SP platform were matched 1:1 without replacement to patients who underwent RARP performed with the da Vinci SP robot according to the nearest-neighbor matching algorithm using a propensity score–based caliper [28] using

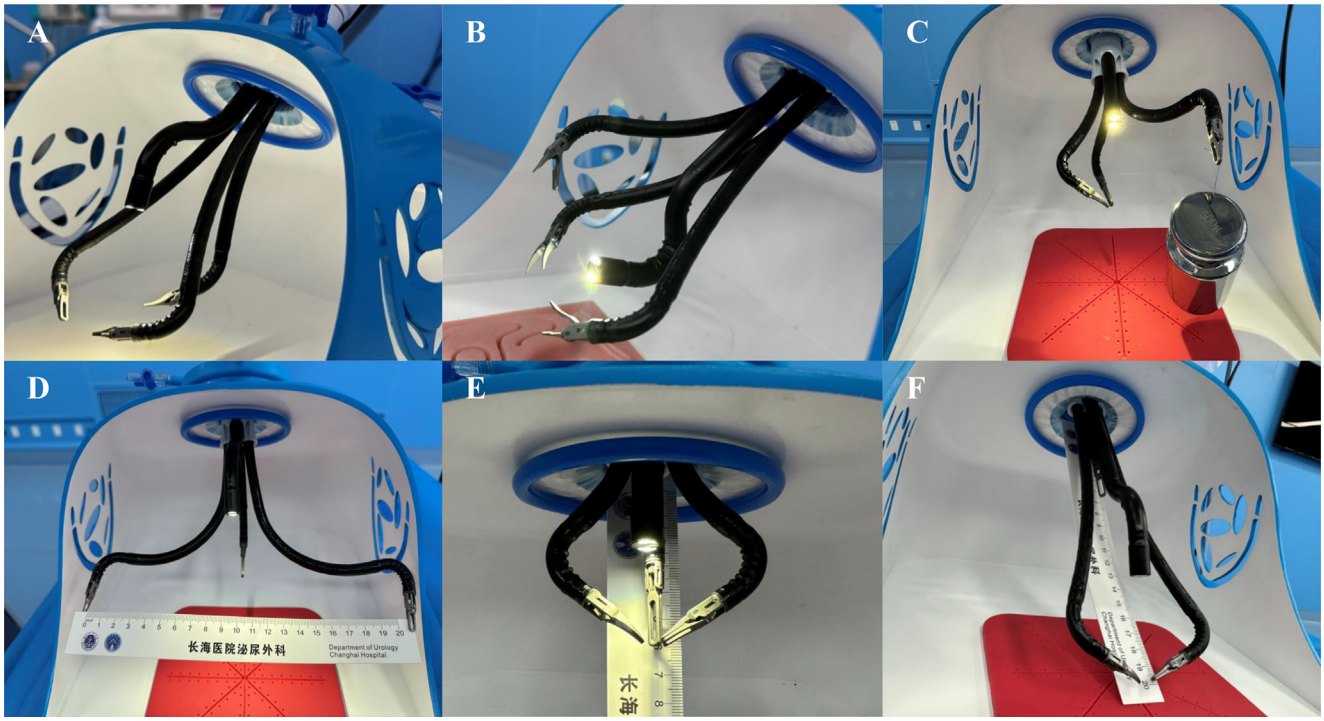

Fig. 4 – Different angulations provided by the SHURUI SP robotic system. Demonstration of the (A,B) forward and reverse cobra modes and (C) payload capability of the flexible endoscope and the wide range for the working space (D) in the bilateral horizontal direction (18 cm) and (E,F) in the longitudinal direction (6–20 cm from the trocar placement).

Table 1 – Technology comparison for the SHURUI SP and da Vinci SP robotic systems

Parameter	SHURUI SP platform	da Vinci SP platform
Approval for clinical use	July 2023, Chinese NMPA	May 2018, US FDA
Product generation	First version	Third version (SP999–SP1098-SP)
Design principle/mechanism	Dual continuum mechanism Core Nitin Arm technology	Wire- and link-driven mechanism
Driving pattern	Pulling and pushing	Pulling only
Key components	Surgeon console	Surgeon console
	Patient cart with vision system integrated	Patient cart Vision system
Workspace configuration	Y type	Y type
Number of robotic arms	1 (camera) + 3 (working)	1 (four arms integrated)
Three-dimensional scope	10 mm × 10 mm, 7 degrees of freedom	12 mm × 1 0mm, 7 degrees of freedom
Quadrant relocation	Patient cart (button control)	Console (separate pedal control)
		Console (pressing the camera pedal and turning the right-hand control since 2021)
Instruments	Diameter 8 mm, 7 degrees of freedom	Diameter 6 mm, 7 degrees of freedom
Triangulation achievement	Continuous deformation	Joints and rigid links
Payload capability	10–18 N	Not reported
Working range		
Longitudinal	7–23 cm	Not reported
Horizontal (bilaterally)	16–20 cm	Not reported
Working instruments	Monopolar curved scissors Cautery hook Maryland bipolar forceps Curved bipolar dissector Fenestrated bipolar forceps Tissue grasper Needle driver	Monopolar curved scissors Maryland bipolar forceps Curved bipolar dissector Fenestrated bipolar forceps Cadiere forceps Needle driver
Instrument tracking system	On the surgeon's display	On the surgeon's display

NMPA = National Medical Products Administration of China; FDA = Food and Drug Administration.

the following covariates: age, body mass index (BMI), American Urological Association (AUA) symptom score, prostate size, PSA, biopsy International Society of Urological Pathology (ISUP) grade group, and D'Amico risk group. A caliper width of one-quarter of the standard deviation of the logit of the propensity score was used.

Descriptive statistics for the SHURUI SP and da Vinci SP groups were obtained, with the median and interquartile range (IQR) reported for continuous variables, and the frequency and proportion reported for categorical variables. Continuous variables were compared using a Wilcoxon test. Differences between categorical variables were assessed

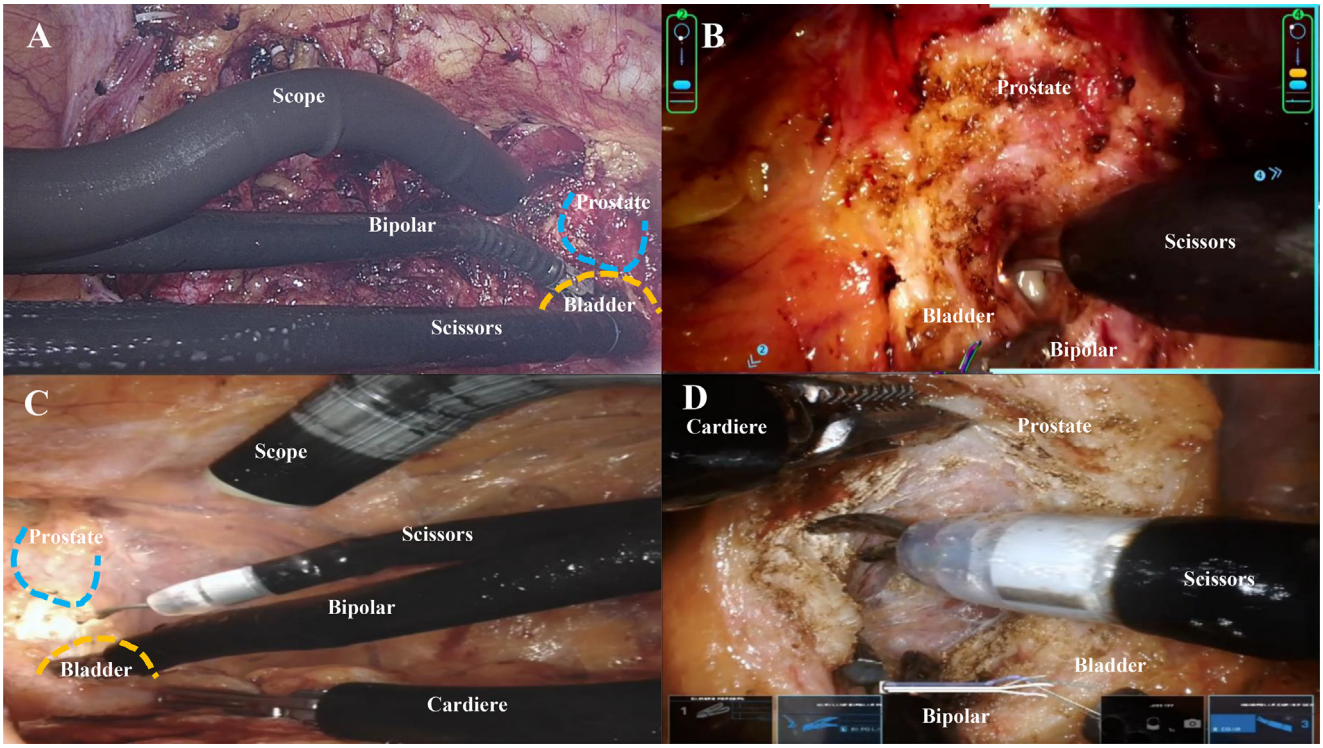

Fig. 5 – Intracorporeal configuration with (A, B) the SHURUI SP robot and (C,D) the da Vinci SP robots during bladder neck dissection. (A, C) View from the assistant trocar angle, recorded with an additional scope and (B, D) view from the robotic endoscopic angle.

using a χ^2 test and Fisher's exact tests, as appropriate. Cumulative incidence functions for continence recovery after surgery were estimated using the Kaplan-Meier method. Statistical analyses were performed using R 4.0.4 software (http://cran.r-project.org). All tests were two-sided, with significance set at $p < 0.05$.

3. Results

3.1. Demographics

Overall, 34 patients underwent RARP performed with the SHURUI SP robot and 100 with the da Vinci SP platform. After 1:1 propensity score matching, the cohort included 27 patients in each group, who had comparable characteristics in terms of age, BMI, AUA symptom score, prostate size, PSA, biopsy ISUP grade group, and D'Amico risk group. Table 2 summarizes the baseline patient characteristics before and after matching.

3.2. Feasibility, safety, and perioperative outcomes

The perioperative characteristics in the overall cohort and after matching are described in Table 3. The surgeries in both groups were successfully completed without any conversions to an alternative surgical approach or unplanned

Table 2 – Baseline characteristics of the study cohorts before and after 1:1 PSM

Variable	Full data set			PSM cohort		
	SHURUI SP (n = 34)	da Vinci SP (n = 100)	p value	SHURUI SP (n = 27)	da Vinci SP (n = 27)	p value
Median age, yr (IQR)	70 (64–74)	62 (56–68)	**<0.001**	69 (64–72)	69 (63–71)	0.883
Median BMI, kg/m^2 (IQR)	24 (22.3–26.5)	25.4 (23.4–27.3)	**0.026**	24.3 (22.6–26.8)	24.1 (22.5–25.9)	0.762
Median preoperative AUA SS (IQR)	6 (4–7)	7 (3–11)	0.367	5 (4–7)	6 (2–10)	0.774
Median total PSA, ng/ml (IQR)	8.5 (4.8–12.6)	5.5 (4.3–7.8)	**0.005**	8.4 (4.3–12.2)	7.1 (5.8–9.7)	1.000
Median prostate volume, cm^3 (IQR)	38 (31–52)	38 (29–49)	0.673	36 (31–52)	42 (30–53)	0.665
Biopsy ISUP grade group, n (%)			0.155			0.583
Grade group 1	15 (44.1)	32 (32)		12 (44.4)	10 (37)	
Grade group 2–3	19 (55.9)	65 (65)		15 (55.6)	17 (63)	
Grade group 4–5	0 (0)	3 (3)		0 (0)	0 (0)	
D'Amico risk group, n (%)			0.412			0.514
Low risk	11 (32.4)	28 (28)		9 (33.3)	8 (29.6)	
Intermediate risk	23 (67.6)	67 (67)		18 (66.7)	17 (63)	
High risk	0 (0)	5 (5)		0 (0)	2 (7.4)	

AUA SS = American Urological Association symptom score; BMI = body mass index; IQR = interquartile range; ISUP = International Society of Urological Pathology; PSA = prostate-specific antigen; PSM = propensity score matching.

Table 3 – Surgical, pathological and follow-up outcomes in the cohorts before and after 1:1 PSM

Variable	Full data set			PSM cohort		
	SHURUI SP (*n* = 34)	da Vinci SP (*n* = 100)	*p* value	SHURUI SP (*n* = 27)	da Vinci SP (*n* = 27)	*p* value
Transperitoneal approach, *n* (%)	8 (23.5)	100 (100)	**<0.001**	5 (18.5)	27 (100)	**<0.001**
Surgical conversion, *n* (%)	0 (0)	0 (0)	–	0 (0)	0 (0)	–
Pure single-port surgery, *n* (%)	10 (29.4)	0 (0)	**<0.001**	7 (25.9)	0 (0)	**0.01**
Median EBL, ml (IQR)	50 (40–105)	50 (50–50)	0.34	50 (40–100)	50 (50–50)	0.539
Transfusion, *n* (%)	0 (0)	0 (0)	–	0 (0)	0 (0)	–
Median total operative time, min (IQR)	217 (174–235)	114 (104–124)	**<0.001**	215 (185–230)	110 (101–118)	**<0.001**
Median console time, min (IQR)	164 (125–193)	80 (75–90)	**<0.001**	162 (130–180)	75 (70–90)	**<0.001**
Degree of nerve sparing, *n* (%)			**<0.001**			**<0.001**
Full	1 (2.9)	50 (50)		1 (3.7)	14 (51.9)	
Partial	1 (2.9)	50 (50)		1 (3.7)	13 (48.1)	
None	32 (94.2)	0 (0)		25 (95.6)	0 (0)	
Pathological ISUP grade group, *n* (%)			0.360			0.088
Grade group 1	9 (26.5)	21 (21)		8 (29.6)	4 (14.8)	
Grade group 2-3	24 (70.6)	72 (72)		18 (66.7)	19 (70.4)	
Grade group 4–5	1 (2.9)	7 (7)		1 (3.7)	4 (14.8)	
Pathological stage ≥T3, *n* (%)	7 (20.6)	24 (24)	0.684	5 (18.5)	6 (22.2)	0.735
Extraprostatic extension, *n* (%)	5 (14.7)	21 (21)	0.423	4 (14.8)	8 (29.6)	0.190
Positive surgical margin, *n* (%)	9 (26.5)	15 (15)	0.132	5 (18.5)	4 (14.8)	1.000
Grade III–IV PO complications, *n* (%)	0 (0)	0 (0)	–	0 (0)	0 (0)	–
PO readmission, *n* (%)	0 (0)	0 (0)	–	0 (0)	0 (0)	–
Median follow-up, mo (IQR)	16 (12–18)	19.8 (16.2–19.9)	0.092	13.5 (12–17.3)	15.9 (13.7–16.2)	0.086
12-mo PSA recurrence, *n* (%)	1 (2.9)	1 (1)	0.445	0 (0)	0 (0)	–
12-mo RRR or metastasis, *n* (%)	0 (0)	0 (0)	–	0 (0)	0 (0)	–
Postoperative UC, *n* (%)			0.822[a]			0.846[a]
At 7 d	0 (0)	4 (4)		0 (0)	2 (7.4)	
At 1 mo	7 (20.6)	31 (31)		4 (14.8)	9 (33.3)	
At 3 mo	23 (67.6)	70 (70)		18 (66.7)	19 (70.4)	
At 12 mo	31 (91.2)	92 (92)		26 (96.3)	26 (96.3)	

EBL = estimated blood loss; IQR = interquartile range; ISUP = International Society of Urological Pathology; PO = postoperative; PSA = prostate-specific antigen; PSM = propensity score matching; RRR = radiological recurrence; UC = urinary continence

[a] Log-rank test for comparison of the cumulative incidence functions.

addition of assistant ports. There were no significant intraoperative complications or major postoperative issues reported for either group. In addition, no patients required readmission.

All the da Vinci SP RARP procedures were performed via a transperitoneal approach and included the use of an assistant trocar, while 81.5% (22/27) of the SHURUI SP cases in the matched cohort were completed via an extraperitoneal approach, with a significantly higher proportion of pure SP procedures (25.9% vs 0%; $p = 0.01$). The median total operative time (215 vs 110 min; $p < 0.001$) and console time (162 vs 75 min; $p < 0.001$) were both significantly longer in the SHURUI group than in the da Vinci group. The proportion of patients who underwent a nerve-sparing procedure was lower in the SHURUI group (7.4% vs 100%; $p < 0.001$). Differences in the positive surgical margin rate (18.5% in the SHURUI group vs 14.8% in the da Vinci group; $p = 1.0$) and the frequency of extraprostatic extension (14.8% vs 29.6%; $p = 0.19$) between the groups were not statistically significant.

3.3. Oncological and functional outcomes at 1 yr

Median follow-up was 13.5 mo (IQR 12–17.3) for the SHURUI group and 15.9 mo (IQR 13.7–16.2) for the da Vinci group ($p = 0.09$) in the matched cohort. There was no difference in the number of patients who experienced biochemical recurrence within the 1-yr follow-up period (1 vs 1; $p = 0.45$). No patients developed radiological recurrence and/or metastasis. Table 3 lists cumulative incidence data for continence, with no significant differences between the groups at 7 d, 1 mo, 3 mo, and 12 mo after surgery. The 1-yr continence rate was 96.3% in both groups (Fig. 6). Postoperative sexual health was not compared because of the patient selection criterion of no preoperative potency in the SHURUI group, so these patients already had erectile dysfunction before surgery.

4. Discussion

To the best of our knowledge, this is the first study comparing the learning process for two commercially available SP robotic platforms. Clinical use of the da Vinci SP platform in the USA was approved by the US Food and Drug Administration in 2018, while the SHURUI SP was approved for use in China by the National Medical Products Administration in 2023. We believed that providing evidence on the technological features and surgical outcomes of the SHURUI SP robot in comparison to the da Vinci SP platform is relevant for patients, surgeons, and health care policymakers. Thus, we conducted a comprehensive comparison of the SHURUI SP and da Vinci SP robots for SP RARP procedures, drawing on data from an international collaboration of referral centers in robotic surgery.

The main difference between the two SP robotic systems lies in the driver mechanism, although both share the common objective of mitigating the SP limitations in instrumental triangulation and addressing the absence of Endo-wrist technology at the tips of the instruments. The da Vinci SP instruments typically consist of multiple joints to triangu-

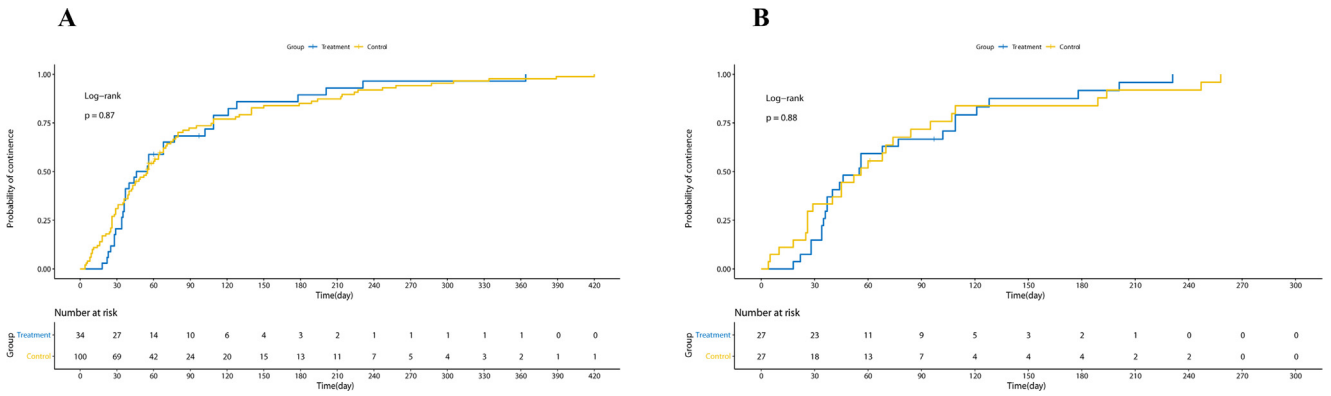

Fig. 6 – Cumulative incidence functions for continence recovery after surgery estimated using the Kaplan-Meier method. Short-term continence recovery (A) in the overall data set and (B) after 1:1 propensity-score matching was similar in the treatment group (SHURUI SP) and the control group (da Vinci SP).

late instruments around the target anatomy. Specifically, wrist-like motion is achieved via coordinated movement of "shoulder/elbow" joints,. However, a greater working distance is needed to facilitate appropriate triangulation and achieve a working space between the instruments. A pair of cables drives each joint, but these cables can only withstand tensile forces when a joint is driven in a particular direction while only one cable pulls the entire surgical arm. The limited load-bearing capacity of a single cable results in restricted overall load-bearing capabilities for the instruments. The maximum bending angle is usually limited, especially at the proximal end of the cable-driven instruments. The inherent limitation of this driving mechanism may be reflected in experiences reported, such as lower traction, dissection, and tissue-gripping capacity with the da Vinci SP robot [23].

The SHURUI SP robot uses an innovative dual-continuum mechanism [12,13], whereby instruments have both a distal end and a proximal end to allow articulation. Dozens of superelastic nitinol rods, which act as backbones with exceptional flexibility, are redundantly arranged along the arms. Bending of a proximal segment is coupled to bending of the distal segment by pulling and pushing of all the redundantly arranged structural backbones (Fig. 1). Hence, the larger proximal end is used as an actuator outside the body, while the thinner distal end acts as the manipulator inside the body. Unlike conventional instruments composed of joints and rigid links, the continuum mechanism achieves motion via continuous deformation of the elastic structure. The external load is evenly distributed across nitinol backbones, thereby enabling the Nitin Arm instruments to offer a large bending angle with high payload capability and reliability (Fig. 4).

Urological surgeries, particularly RP for prostate cancer, have consistently been among the first procedures undertaken when introducing new robotic systems into clinical practice. This surgical procedure serves as an excellent benchmark for evaluating the performance of novel robotic surgical systems [1,14,29]. Comparison of intraoperative RARP performance can facilitate a better understanding of differences in robot technology and how these differences may account for the findings observed. The first difference is in the frequency of an extraperitoneal surgical approach, which might be associated with the working distance. The extraperitoneal approach is preferred when using the SHURUI SP robot, while all cases were performed via a transperitoneal approach with the da Vinci SP in the matched cohort. Besides the surgeon's personal preference, this distinction may be attributed in part to the spatial requirements of the robotic systems. The SHURUI SP robot requires a minimum in vivo deployment space of 6–7 cm, making it more suited for the extraperitoneal space without using the "floating trocar" technique, in contrast to the minimum deployment space of 10–12 cm for the da Vinci SP robot. In the initial da Vinci SP RARP series reported by Vigneswaran et al [30], 90% (45/50) of the cases were performed via a transperitoneal approach. During early application of the da Vinci SP system, Kaouk et al [31] explored an extraperitoneal approach, identifying its potential to accelerate recovery and lessen postoperative pain. However, the authors also emphasized the critical need for sufficient space to effectively deploy and maneuver the surgical instruments, which is a key factor in the success of the technique [32]. Nevertheless, as mentioned earlier, the space issue encountered with the da Vinci SP robot when performing extraperitoneal SP surgery can be mitigated using a GelPOINT system or a da Vinci SP Access Kit (Intuitive Surgical) for the "floating trocar" technique [10,11,31], although this would increase direct surgical costs.

The second difference is the proportion of pure SP surgeries without use of an additional port achieved during the very early learning stage. Approximately one-quarter of the SHURUI SP cases were completed without a need for any additional assistant trocar. This may partly reflect the adequate payload capability of the SHURUI SP instruments in terms of traction, dissection, and tissue-gripping ability. Nonetheless, pioneer experiences highlighted that use of an auxiliary assistant port ("single port plus one") is still recommended for safe management of the learning process [33]. The SHURUI SP has a larger bending angle (approx. 135°) for instruments, which may decrease the need for frequent relocation to move the whole camera-instrument block to retarget the anatomy of interest.

Finally, there may be a difference in the incidence of instrument clashes between the two robots. The cable-

driven da Vinci SP instruments extend out from the trocar (entry guide) with clustered straight stems. Only the distal portion of the instruments can separate from each other via sideways motion of the elbow joints. Thus, collisions are potentially more frequent between the elbow joints and the straight stems, especially when the instruments suffer external force over large insertion lengths. By contrast, the SHURUI SP snake-like instruments begin to bend at the very base of the segments near the trocar, which enhances the sideways motion capability of the instruments, improves the triangulation for surgery, and avoids mutual collision of the instruments.

Our analysis demonstrated that total operative and console times were longer for the SHURUI SP group, although they were comparable to times reported from initial studies on the da Vinci SP robot [30]. The differences may also be explained by the surgeon's experience with multiport RARP, which undoubtedly has an impact during initial implementation of the SP approach. Indeed, while the da Vinci SP cases included in our study were performed by a lead surgeon who had carried out more than 17 000 RP interventions before starting his SP experience, the three surgeons performing RP interventions with the SHURUI SP each had personal robotic surgery experience of less than 2000 cases, with an annual average of 100–200 RP procedures. Comparison of intraoperative performance revealed a much lower rate of nerve-spring surgery in the SHURUI SP group, which was related to the selection criteria, as patients SHURUI group were not potent before surgery. We believe that this selection criterion is appropriate from an ethical point of view, particularly because of the initial learning-curve period.

The positive margin rate in the SHURUI SP group (18.5%) was not significantly different to the 15% observed in the da Vinci group in the matched cohort. This rate also aligns with data from the early da Vinci SP series, indicating consistency in surgical outcomes between the two groups [34]. In addition, data for our unmatched cohort align closely (or are even superior in some cases) with those reported by other teams performing da Vinci SP RARP, suggesting broader consistency of surgical results across different groups using this technology [30,35–37]. Finally, we did not find any significant difference between the two robots in terms of oncological safety over short-term follow-up and continence recovery, suggesting that the platforms are equally effective at performing RARP.

Despite its originality, our study has several limitations inherent to its retrospective design. The patient selection criteria included individuals with early-stage prostate cancer and without preoperative sexual function, which may limit the generalizability of the findings. In addition, the overall sample size is relatively small, affecting the robustness and statistical power of the results. There is a notable disparity in the number of procedures performed and the level of surgeon experience between the two robotic systems. The retrospective nature of the study introduces potential biases and limits possible control over variables, despite our efforts to closely match conditions. Furthermore, the follow-up period of 1 yr is rather short for evaluation of oncological outcomes, so longer-term follow-up is needed to fully assess clinical endpoints and functional recovery. The analysis predominantly relied on a static comparison of specifications owing to a lack of detailed dynamic performance data for the SP components, constraining our ability to perform a comprehensive experimental comparison of the operational performance of the two robotic systems. Differences in racial characteristics and pelvic dimensions between the two groups may account for the differences in surgical space when performing SP RARP. Nevertheless, our study is significant as it is the first to compare technological differences and outcomes for two platforms specifically designed for SP RARP. Studies with larger sample sizes, extended follow-up, and detailed dynamic performance data are required to validate and extend our findings.

Technological malfunctions are inevitable in any novel system, and this is precisely where surgeons can assist in making improvements during clinical application. A few issues were encountered during clinical use of the SHURUI SP platform. Insertion and removal of instruments from the robotic arms can be somewhat laborious. If the contact surface on the robotic arm is not properly aligned (ie, not reset to its initial position), forcible attachment of instruments may render them unusable and difficult to remove, necessitating a system restart. Fortunately, the restart process is relatively quick, and these issues typically arise in the initial setup and testing stage during the docking phase. As familiarity and proficiency increase, such errors occur less frequently and generally do not significantly impact the surgical procedure. Future iterations of the system will consider these issues for improvement. One occasional issue is failure to read instrument information, usually caused by improper installation of an instrument. The solution is to reinstall the instrument correctly. Another issue is failure to acquire a monocular image after installing the endoscope. The solution is to reconnect the endoscope connector. None of these issues have been severe enough to compromise surgical safety, but there is still room for improvement. It is hoped that future iterations of the system will fix these issues.

5. Conclusions

Despite differences in the driving mechanism in comparison to the da Vinci SP robotic system, the SHURUI SP platform allows safe and effective RARP during the initial learning phase and yields similar short-term oncological and continence outcomes. Further research with a larger population and longer follow-up is warranted.

Author contributions: Linhui Wang had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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Drafting of the manuscript: Wu.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.euros.2024.07.107.

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