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RESEARCH

Performance and safety of Kangduo surgical robot versus da Vinci robotic system for urologic surgeries

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Abstract

Objective Kangduo (KD) surgical robot is a novel robotic system in China, and some animal experiments and single-arm clinical trials have indicated its effectiveness, feasibility, and safety for urologic surgeries. This study intended to compare the performance and safety of the KD surgical robot with the da Vinci (DV) robotic system in patients who received urologic surgeries.

Methods A total of 201 patients who received urologic surgeries were divided into the KD group ($N=60$) and the DV group ($N=141$) according to the actual surgical methods.

Results The median (range) operation time [180.0 (30.0-540.0) minutes vs. 130.0 (70.0-360.0) minutes] ($P<0.001$) and indwelling time of abdominal drainage tube [5.0 (2.0–14.0) days vs. 3.0 (2.0–18.0) days] ($P<0.001$) were longer, but the intraoperative blood loss [50.0 (10.0-200.0) mL vs. 50.0 (10.0-400.0) mL] ($P<0.001$) was less in the KD group than the DV group. The median values of white blood cells at the 1st ($P=0.032$) and 3rd ($P=0.022$) day after surgery were decreased in the KD group compared to the DV group. The incidence of infection (11.7% vs. 29.1%) ($P=0.008$) and fever (15.0% vs. 30.5%) ($P=0.023$) was lower in the KD group compared to the DV group. Postoperative and follow-up parameters, including time of urinary incontinence improvement, administration of hemostatic, pain numeric rating scale score, Barthel's index score, and patient satisfaction, were not different between the two groups (all $P>0.05$).

Conclusion The KD surgical robot unveils satisfactory surgical performance compared to the DV robotic system in patients receiving urologic surgeries.

Keywords Urologic surgeries · Kangduo surgical robot · Da Vinci robotic system · Performance · Complications

Introduction

Robotic systems for urologic surgeries, such as nephrectomy, prostatectomy, and pyeloplasty, have improved surgical outcomes in patients with urologic diseases [1–3]. The da Vinci (DV) robotic system is the most widely used surgical robot worldwide, dominating the market for nearly two decades, with the advantages of magnified stereoscopic vision, minimal invasion, and good accuracy and dexterity [4–6]. Despite its various benefits, there are still some concerns regarding the DV robotic system, such as high costs, which hinder its application [7, 8]. Furthermore, the occurrence of surgical complications is also a concern of the DV robotic system, which prolongs hospitalization and reduces the quality of life in patients with urologic diseases [9, 10]. Therefore, exploring potential robotic surgical systems for urologic surgeries is meaningful to improve the management of patients with urologic diseases.

Several companies have already developed surgical robots that could potentially rival the DV robotic system, such as Senhance®, Revo-I®, Versius®, Avatera®, Hinotori®, and Hugo™ RAS [6]. However, the performance of these robots still could not compare with that of the DV robotic system [6].

The Kangduo (KD) surgical robot is a recently developed robotic system in China, which is a master-slave system and consists of a surgeon console, patient cart, and vision

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cart [11]. The KD surgical robot, compatible with 3D high-definition endoscopy, enables surgeons to precisely access surgical areas in complex surgical environments and fully replicate the surgeon's operational intentions in the patient's surgical site through a master-slave control system [11]. Currently, some animal experiments [12–14] and single-arm clinical trials [15–18] have suggested that the KD surgical robot is effective, feasible, and safe for urologic surgeries.

Accordingly, the current study aimed to compare the performance and safety of the KD surgical robot and the DV robotic system in these patients.

Methods

Patients

Between October 2023 and April 2024, 201 patients who received urologic surgeries with the KD surgical robot or DV robotic system were included in the study. The inclusion criteria contained: (1) aged over 18 years; (2) received urologic surgeries with KD surgical robot or DV robotic system; (3) American Society of Anesthesiologists (ASA) score of I or II; (4) had complete clinical data for the study analysis. The exclusion criteria contained: (1) previously received abdominal surgery; (2) pregnancy or lactation. The study had the approval from the Ethics Committee of Harbin Medical University Cancer Hospital, and the approval number was 2023-301-QX-IIT. Each patient or his/her family member signed informed consent.

Treatment

Patients received urologic surgeries with a KD surgical robot or DV robotic system according to the actual disease condition, patient willingness, and the surgeon's advice. Then, patients were divided into the KD group and the DV group. The urologic surgeries included partial or radical nephrectomy, partial or radical cystectomy, radical prostatectomy, adrenalectomy, radical resection of ureteral tumor, retroperitoneal tumor resection, pyeloureteroplasty, inguinal lymph node dissection, radical resection of scrotal skin lesions, and retroperitoneal lymph node dissection. Lymph node dissection was performed in patients receiving radical surgeries. The surgeries were conducted by surgeons who possessed over 10 years of experience and held the title of Senior Chief Physician or above. The KD surgical robot was shown in Fig. 1A-D.

The KD surgical robot was emerging as a promising technology in China, and a KD surgical robot-assisted prostatectomy was described in detail in the following section as an example. The subumbilical incision was made into the rectus sheath, and the extraperitoneal space was extended under the rectus abdominis. Following the incision of the endopelvic fascia, the dorsal venous complex was sutured and ligated (Fig. 2A), and the puboprostatic ligaments were suspended. After determining the interface between the prostate and bladder neck, the anterior bladder neck was separated with a monopolar scissor (Fig. 2B). The seminal vesicles were then dissected (Fig. 2C), exposing the recto-prostatic fascia. The seminal vesicle was retracted, revealing the ipsilateral neurovascular pedicle. The prostatic pedicles were then clipped and detached (Fig. 2D). The urethra was

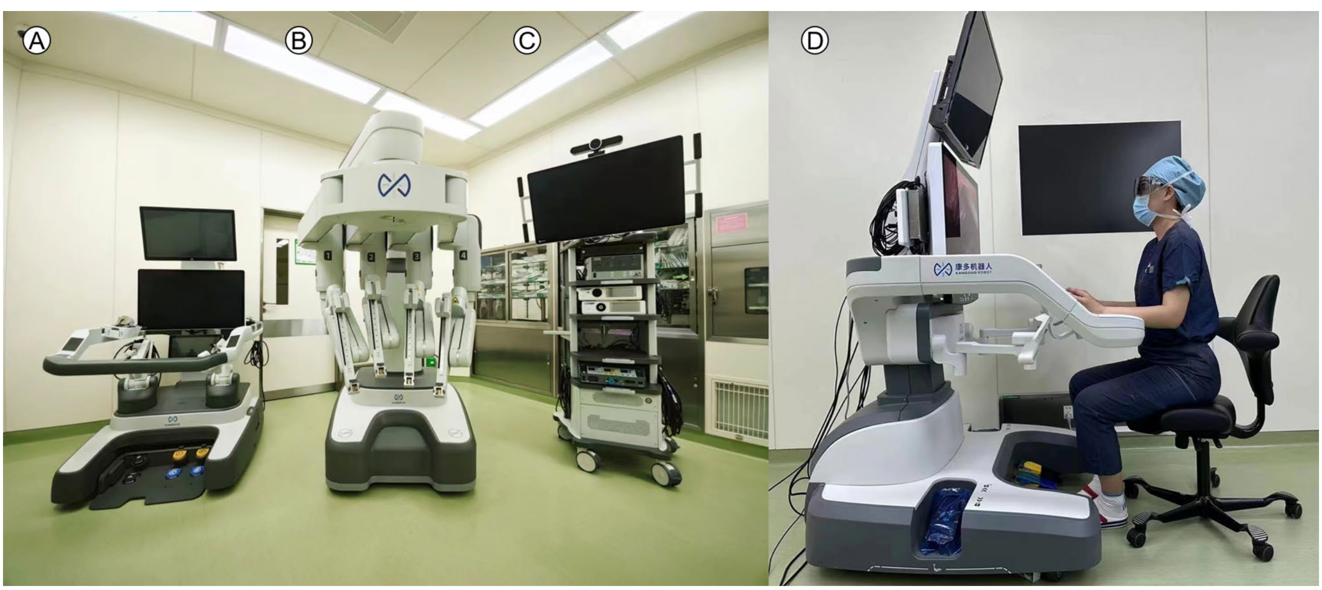

Fig. 1 The KD surgical robot. The surgeon control console (**A**). The patient cart (**B**). The vision cart (**C**). The surgeon sitting in front of the open console of the KD (**D**)

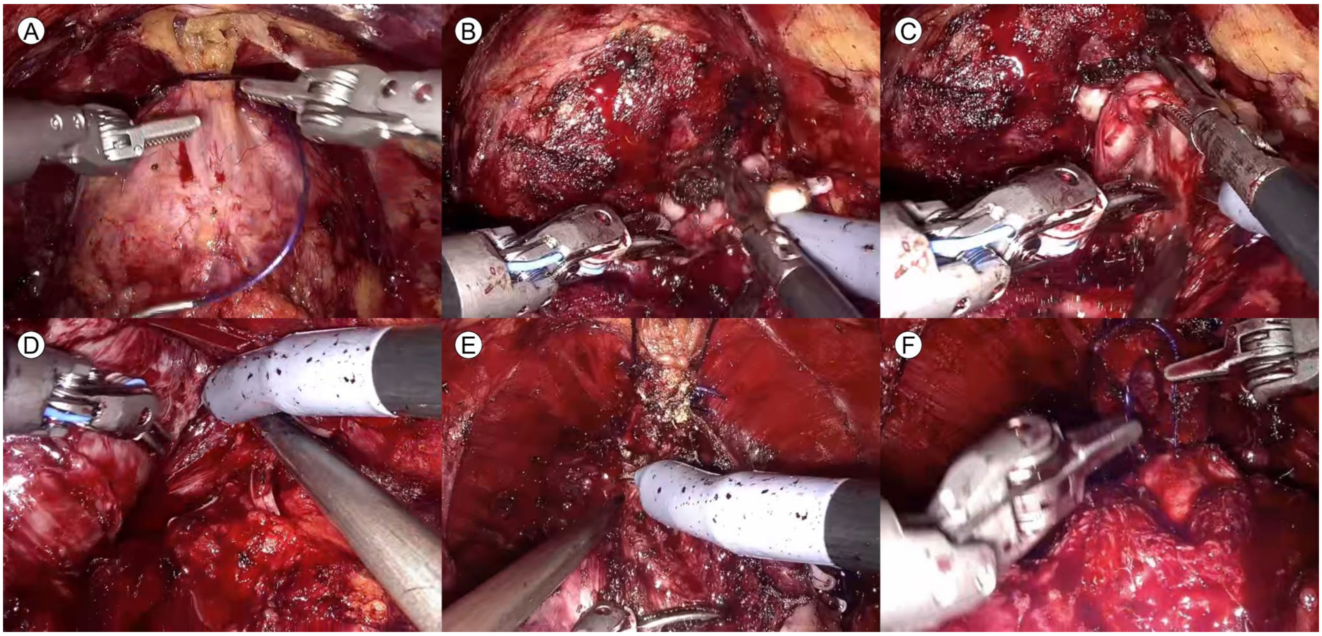

Fig. 2 Surgical technique of prostatectomy with the KD surgical robot. Suturing-ligation of the dorsal venous plexus (**A**). Bladder neck dissection (**B**). Preparation of the seminal vesicles (**C**). Dissection of the rectoprostatic fascia (**D**). Disconnection of the urethra (**E**). Vesicourethral anastomosis (**F**)

subsequently split (Fig. 2E), and posterior musculofascial repair was performed. The vesicourethral anastomosis was done using two barbed sutures (Fig. 2F). For other urologic surgeries performed with KD surgical robot assistance, the operations were also conducted and were detailed in previous reports [16]. The detailed elaboration of operations with DV robotic system assistance was not described in the study due to its established use, which could be found in the previously published study [19].

Data collection and assessment

The clinical characteristics of patients were collected, which contained: (1) basic characteristics: age, sex, diagnosis, and surgical type; (2) intraoperative and perioperative parameters: operation time, intraoperative blood loss, intraoperative blood transfusion, drainage volume within 24 h after surgery, urine output within 24 h after surgery, indwelling time of abdominal drainage tube, time to first flatus, and length of stay; (3) postoperative biochemical indexes: urea nitrogen, serum creatinine, white blood cell, and neutrophil percentage; (4) complications: infection, fever (defined as body temperature > 38.5 °C for at least 3 days), acute kidney injury, and urinary incontinence; (5) postoperative and follow-up information: time of urinary incontinence improvement, administration of hemostatic, pain numeric rating scale (NRS) score at 1st day after surgery (D1), Barthel's index score at 3rd day after surgery (D3), and patient satisfaction. Pain NRS score ranged from 0 to 10, with a higher score indicating a higher pain level. Barthel's index score was used for self-care assessment with a range of 0-100, and a higher score indicated a better self-care ability [20]. Patient satisfaction was assessed with a 5-point Likert scale, including very satisfied, satisfied, neutrality, unsatisfied, and very unsatisfied [21].

Statistics

SPSS v.26.0 (IBM, USA) was used for analyses. The clinical data were shown using mean ± standard deviation, median (range), or No. (percentage). The comparisons were analyzed accordingly using a t-test, Wilcoxon rank sum test, or Chi-square test or Fisher's exact test. $P < 0.05$ indicated statistical significance.

Results

Clinical features in the KD and DV groups

This study contained 201 patients, with 60 patients in the KD group and 141 patients in the DV group. The mean age was 63.0 (32.0–82.0) years in the KD group and 61.0 (21.0–92.0) years in the DV group ($P = 0.494$). There were 19 (31.7%) females and 41 (68.3%) males in the KD group as well as 45 (31.9%) females and 96 (68.1%) males in the DV group ($P = 0.972$). The disease types and surgical types were different between the two groups (both $P < 0.001$). The

Table 1 Basic characteristics

Items	DV group (N=141)	KD group (N=60)	P value
Age (years)	61.0 (21.0–92.0)	63.0 (32.0–82.0)	0.494
Sex			0.972
Female	45 (31.9)	19 (31.7)	
Male	96 (68.1)	41 (68.3)	
Diagnosis			<0.001
Kidney cancer	97 (68.8)	35 (58.3)	
Bladder cancer	1 (0.7)	11 (18.3)	
Prostatic cancer	29 (20.6)	5 (8.3)	
Adrenal cancer	10 (7.1)	2 (3.3)	
Others*	4 (2.8)	7 (11.7)	
Surgical type			<0.001
Nephrectomy	100 (70.9)	34 (56.7)	
Cystectomy	1 (0.7)	10 (16.7)	
Prostatectomy	29 (20.6)	5 (8.3)	
Adrenalectomy	7 (5.0)	1 (1.7)	
Others#	4 (2.8)	10 (16.7)	

*, Other diagnoses included ureteral cancer, retroperitoneal cancer, scrotum cancer, and testicular cancer. #, other surgical types included radical resection of ureteral tumor, retroperitoneal tumor resection, pyeloureteroplasty, inguinal lymph node dissection, radical resection of scrotal skin lesions, and retroperitoneal lymph node dissection. Age was shown using median (range) and analyzed using Wilcoxon rank sum test; other characteristics were shown using No. (percentage) and analyzed using Chi-square test or Fisher's exact test. DV, Da Vinci; KD, KangDuo

detailed clinical information of the two groups is shown in Table 1.

Comparison of intraoperative and perioperative parameters between the KD and DV groups

Operation time [median (range): 180.0 (30.0-540.0) minutes vs. 130.0 (70.0-360.0) minutes] ($P<0.001$) and indwelling time of abdominal drainage tube [median (range): 5.0 (2.0–14.0) days vs. 3.0 (2.0–18.0) days] ($P<0.001$) were longer in the KD group than in the DV group. Intraoperative blood loss was decreased in the KD group compared to the DV group [median (range): 50.0 (10.0-200.0) mL vs. 50.0 (10.0-400.0) mL] ($P<0.001$). Other intraoperative and perioperative parameters were not different between the two groups (all $P>0.05$) (Table 2).

Subgroup analysis for intraoperative and perioperative parameters based on specific diagnoses and surgical types

In kidney cancer patients with nephrectomy, intraoperative blood loss was less, indwelling time of abdominal drainage tube was longer, and the length of stay was shorter in the KD group than in the DV group (all $P<0.05$). In bladder cancer patients with cystectomy, intraoperative blood transfusion was less in the KD group than in the DV group

Table 2 Intraoperative and perioperative parameters

Items	DV group (N=141)	KD group (N=60)	P value
Operation time (minutes)			<0.001
Mean ± standard deviation	142.0 ± 50.1	197.1 ± 103.4	
Median (range)	130.0 (70.0-360.0)	180.0 (30.0-540.0)	
Intraoperative blood loss (mL)			<0.001
Mean ± standard deviation	78.2 ± 60.9	48.7 ± 38.4	
Median (range)	50.0 (10.0-400.0)	50.0 (10.0-200.0)	
Intraoperative blood transfusion (mL)			0.609
Mean ± standard deviation	22.7 ± 68.0	16.7 ± 55.7	
Median (range)	0.0 (0.0-400.0)	0.0 (0.0-200.0)	
Drainage volume within 24 h after surgery (mL)			0.278
Mean ± standard deviation	77.2 ± 58.9	78.9 ± 50.8	
Median (range)	67.0 (21.0-455.0)	75.0 (9.0-400.0)	
Urine output within 24 h after surgery (mL)			0.767
Mean ± standard deviation	1916.4 ± 511.7	1940.6 ± 541.8	
Median (range)	2000.0 (150.0-3000.0)	1900.0 (200.0-3100.0)	
Indwelling time of abdominal drainage tube (days)			<0.001
Median (range)	3.0 (2.0–18.0)	5.0 (2.0–14.0)	
Time to first flatus (days)			0.253
Median (range)	3.0 (2.0–5.0)	3.0 (1.0–5.0)	
Length of stay (days)			0.813
Median (range)	8.0 (5.0–18.0)	8.0 (5.0–20.0)	

All characteristics were shown using mean ± standard deviation and median (range), and analyzed using Wilcoxon rank sum test. DV, Da Vinci; KD, KangDuo

Table 3 Postoperative biochemical indexes

Items	DV group (N=141)	KD group (N=60)	P value
Urea nitrogen at D1 (mmol/L)			0.860
Mean ± standard deviation	6.0 ± 1.3	5.9 ± 1.5	
Median (range)	6.3 (2.7–8.7)	5.9 (2.8–8.9)	
Serum creatinine at D1 (μmoI/L)			0.818
Mean ± standard deviation	81.7 ± 16.3	81.7 ± 16.4	
Median (range)	78.8 (46.0-101.7)	78.7 (56.3-134.7)	
White blood cell at D1 (10^9/L)			0.032
Mean ± standard deviation	9.5 ± 3.5	8.3 ± 2.7	
Median (range)	8.1 (4.5–17.8)	7.4 (4.5–14.5)	
Neutrophil percentage at D1 (%)			0.353
Mean ± standard deviation	71.8 ± 13.6	69.2 ± 14.2	
Median (range)	67.9 (45.7-134.7)	67.6 (34.2–99.0)	
White blood cell at D3 (10^9/L)			0.022
Mean ± standard deviation	8.2 ± 2.7	7.1 ± 1.9	
Median (range)	7.5 (4.4–15.7)	6.5 (3.6–11.3)	
Neutrophil percentage at D3 (%)			0.082
Mean ± standard deviation	64.4 ± 14.4	60.7 ± 11.4	
Median (range)	64.3 (34.2-113.1)	60.2 (34.8–86.5)	

All characteristics were shown using mean ± standard deviation and median (range), and analyzed using Wilcoxon rank sum test. DV, Da Vinci; KD, KangDuo; D1, 1st day after surgery; D3, 3rd day after surgery

Table 4 Complications

Items	DV group (N=141)	KD group (N=60)	P value
Infection	41 (29.1)	7 (11.7)	0.008
Fever	43 (30.5)	9 (15.0)	0.023
Acute kidney injury	6 (4.3)	4 (6.7)	0.489
Urinary incontinence*	5 (17.2)	3 (60.0)	0.072

All characteristics were shown using No. (percentage) and analyzed using Chi-square test or Fisher's exact test. *, urinary incontinence was only assessed in patients receiving prostatectomy. DV, Da Vinci; KD, KangDuo

(P=0.002). In prostatic cancer patients with prostatectomy, operation time was longer, intraoperative blood loss was less, and indwelling time of abdominal drainage tube and length of stay were shorter in the KD group than in the DV group (all P<0.05). In adrenal cancer patients with adrenalectomy, the intraoperative and perioperative parameters are not different between the two groups (all P>0.05) (Supplementary Table 1).

Comparison of postoperative biochemical indexes and complications between the KD and DV groups

White blood cells at D1 [median (range): 7.4 (4.5–14.5)×10^9/L vs. 8.1 (4.5–17.8)×10^9/L] (P=0.032) and D3 [median (range): 6.5 (3.6–11.3)×10^9/L vs. 7.5 (4.4–15.7)×10^9/L] (P=0.022) were lower in the KD group than in the DV group. Other postoperative biochemical indexes were not different between the two groups (all P>0.05) (Table 3).

Regarding complications, the rates of infection (11.7% vs. 29.1%) (P=0.008) and fever (15.0% vs. 30.5%) (P=0.023) were decreased in the KD group compared to the DV group. However, the rates of acute kidney injury and urinary incontinence were not different between the two groups (both P>0.05) (Table 4).

Subgroup analysis for complications based on different surgical types

In patients receiving nephrectomy, cystectomy, and other surgeries, infection, fever, and acute kidney injury were not different between the DV and KD groups (all P>0.05). In patients receiving prostatectomy, infection, fever, acute kidney injury, and urinary incontinence did not differ between the two groups (all P>0.05). In patients receiving adrenalectomy, infection and fever were not different between the two groups (both P>0.05) (Supplementary Table 2).

Comparison of postoperative and follow-up information between the KD and DV groups

Time of urinary incontinence improvement (P=0.786), administration of hemostatic (P=0.679), pain NRS score (P=0.055), Barthel's index score (P=0.558), or patient satisfaction (P=0.628) was not different between the two groups (Table 5).

Table 5 Postoperative and follow-up information

Items	DV group (N=141)	KD group (N=60)	P value
Time of urinary incontinence improvement*			0.786
0.5 months	1 (20.0)	0 (0.0)	
2 months	2 (40.0)	0 (0.0)	
3 months	1 (20.0)	2 (66.7)	
6 months	1 (20.0)	1 (33.3)	
Administration of hemostatic	22 (15.6)	8 (13.3)	0.679
Pain NRS score	2.7±0.5	2.5±0.5	0.055
Barthel's index score	68.7±5.1	68.2±6.0	0.558
Patient satisfaction			0.628
Very satisfied	136 (96.5)	57 (95.0)	
Satisfied	2 (1.4)	1 (1.7)	
Neutrality	3 (2.1)	2 (3.3)	
Unsatisfied	0 (0.0)	0 (0.0)	
Very unsatisfied	0 (0.0)	0 (0.0)	

Pain NRS score and Barthel's index score were shown using mean±standard deviation and analyzed using t-test; other characteristics were shown using No. (percentage) and analyzed using Chi-square test or Fisher's exact test. *, time of urinary incontinence improvement was assessed among patients receiving prostatectomy who had urinary incontinence during follow-up. DV, Da Vinci; KD, KangDuo; NRS, numeric rating scale

Discussion

The emergence of robotic surgical platforms brings non-negligible benefits for patients receiving urologic surgeries [22–25]. KD surgical robot is a newly developed robotic surgical system in China, and several studies have compared the performance of this surgical robot with the DV robotic system in patients who receive gastrointestinal and urologic surgeries [26–30]. Regarding urologic surgeries, two studies indicated that the KD surgical robot for prostatectomy and pyeloplasty led to a longer operation time than the DV robotic system [26, 28]. In line with previous studies [26, 28], we discovered that the operation time was longer in patients who received the KD surgical robot-assisted urologic surgeries than in those who received the DV robotic system-assisted urologic surgeries. A possible reason would be that, by comparison with the DV robotic system, physicians would be unfamiliar with the operation of the KD surgical robot and they would need more time to master this technology, leading to a long operation time [27]. We also discovered that the KD surgical robot resulted in a prolonged indwelling time of the abdominal drainage tube compared to the DV robotic system in patients who received urologic surgeries. A potential explanation would be that compared with the DV robotic system, the KD surgical robot was a novel technology, and physicians might be cautious about patients' postoperative conditions [11, 26, 27]. Therefore, the indwelling time of the abdominal drainage tube was prolonged to monitor patients' recovery and prevent complications in patients receiving the KD surgical robot-assisted urologic surgeries. Another finding was that the KD surgical robot contributed to less intraoperative blood loss compared to the DV robotic system. A possible reason might be that the DV robotic system was a well-established technology compared with the KD surgical robot [5, 11, 31], which was mainly applied in complicated surgeries, such as nephrectomy and prostatectomy, in this study. Therefore, more intraoperative blood loss was found in patients who received the DV robotic system-assisted urologic surgeries than those who received the KD surgical robot-assisted urologic surgeries.

Postoperative complications are major concerns when considering applying new technologies, and several previous studies indicated that postoperative complications were not different between patients receiving the KD surgical robot-assisted urologic surgeries and those receiving the DV robotic system-assisted urologic surgeries [26–28]. In the current study, we found that infection and fever were decreased in patients receiving the KD surgical robot-assisted urologic surgeries compared to those receiving the DV robotic system-assisted urologic surgeries. A possible reason would be that the KD surgical robot was a relatively new technology compared with the DV surgical robot, physicians and nurses might pay more attention to patients' postoperative management, leading to a lower occurrence of infection and fever. It should be clarified that no preoperative antibiotic prophylaxis was administered to any patients in this study. It was also found that white blood cells at D1 and D3 were decreased in patients receiving the KD surgical robot-assisted urologic surgeries compared to those receiving the DV robotic system-assisted urologic surgeries, which could be attributed to the lower incidence of infection [32, 33]. However, other postoperative complications and biochemical indexes did not differ between patients who received the KD surgical robot-assisted urologic surgeries and those who received the DV robotic system-assisted urologic surgeries, suggesting the comparable safety of the KD surgical robot to the DV surgical robot in patients who received urologic surgeries. However, the postoperative complications might not be related to the use of surgical robots.

Urinary continence recovery is an important issue after urologic surgeries, and one previous study indicated that urinary continence recovery was not affected by the KD surgical robot or the DV robotic system in patients receiving prostatectomy [26]. Consistent with this previous study [26], we also discovered that the urinary incontinence improvement was not affected by the KD surgical robot or the DV robotic system in patients receiving urologic surgeries. Apart from that, we found that the impact of the KD surgical robot on postoperative bleeding, pain, self-care ability, and patient satisfaction was comparable to the DV robotic system in patients receiving urologic surgeries. Overall, our findings disclosed that the KD surgical robot possessed comparable performance to the DV robotic system in patients receiving urologic surgeries. Importantly, the estimated cost of the KD surgical robot was about 25–30% of that of the DV robotic system [16, 27]. Therefore, the KD surgical robot might be a promising surgical technology for patients who received urologic surgeries.

Considering that this study included patients with different diagnoses and surgical types, subgroup analyses were conducted. It was found that some intraoperative and perioperative parameters, such as intraoperative blood loss, intraoperative blood transfusion, and length of study, were better in the KD group than in the DV group, in the subgroup of kidney cancer patients with nephrectomy, bladder cancer patients with cystectomy, and prostatic cancer patients with prostatectomy. All intraoperative and perioperative parameters were not different between the KD and DV groups, in the subgroup of adrenal cancer patients with adrenalectomy. Additionally, all complications were not affected by different surgical types. Some of the results from the subgroup analyses were inconsistent with our main findings. Therefore, further randomized, controlled trials were required to further compare the performance between the KD surgical robot and the DV robotic system.

This was an observational study, and we did not interfere with patients' choice of surgical robots. The choice of surgical robots was based on physicians' advice, disease conditions, and patient's willingness. Clinically, we thought that the difference in the number of patients in the two groups and the number of patients receiving different surgeries in the two groups might be related to the maturity of technology and economic factors.

Several limitations should be noted in this study. (1) The number of patients was unmatched in the DV group and the KD group, which might influence the outcomes of this study. (2) Although subgroup analysis based on specific diagnoses and surgical types was conducted, the number of patients was unbalanced, and some baseline features might be different between the two groups. Therefore, further randomized controlled trials that restricted the surgical type were needed to validate the findings of our study. (3) To support the wide application of the KD surgical robot, the cost-effectiveness comparison between the KD surgical robot and the DV robotic system was required, which could be a direction for subsequent studies.

In conclusion, the KD surgical robot shows good surgical performance compared to the DV robotic system in patients receiving urologic surgeries. Considering the high cost of the DV robotic system and the demand for the evolution of surgical robot systems, the KD surgical robot may possess the potential to serve as an optional choice for patients who receive urologic surgeries. Moreover, the performance of the KD surgical robot seems better than the DV robotic system in kidney cancer patients with nephrectomy, bladder cancer patients with cystectomy, and prostatic cancer patients with prostatectomy. However, further randomized, controlled trials are warranted.

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Author contributions Fengjiao Wang and Xuexin Li contributed to the study conception and design. Material preparation and data collection were performed by Fengjiao Wang and Xuexin Li. Data analysis was performed by Yanan Liu. The first draft of the manuscript was written by Fengjiao Wang and Xuexin Li. Yanan Liu and Xuexin Li revised the manuscipt. All authors read and approved the final manuscript.

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Data availability The data supporting this study has been prepared and can be obtained for valid reasons by contacting the corresponding author via email.

Declarations

Competing interests The authors declare no competing interests.

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