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Laparoscopic renal surgery using multi degree-of-freedom articulating laparoscopic instruments in a porcine model

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Purpose: We evaluated the performance of a new multi-degree-of-freedom articulating laparoscopic instrument, ArtiSential, and compared it with that of a straight-shaped instrument and the da Vinci surgical system, in renal surgery using porcine model.
Materials and Methods: Nine female Yorkshire pigs were equally divided into three groups. The three groups were compared at each surgical step in terms of objective and subjective parameters.
Results: The median operative times for renal pedicle clamping and ureter dissection were significantly shorter in ArtiSential group than robotic group (1.3 min vs. 4.7 min, p=0.002; 8.1 min vs. 11.1 min, p=0.015). The median operative time for bladder repair was significantly longer in ArtiSential group than robotic and straight-shaped groups (17.9 min vs. 5.5 min, p=0.002; 17.9 min vs. 9.3 min, p=0.026). There were no significant differences among groups in terms of blood loss or intraoperative complications. ArtiSential device was less useable for renorrhaphy (p=0.009) and bladder repair (p=0.002) compared to the robotic system. ArtiSential group was less accurate than robotic group in terms of tumor resection, renorrhaphy, and bladder repair. During ureter dissection, bladder cuff excision, and bladder repair, the surgeon experienced greater wrist discomfort but lesser back discomfort in ArtiSential group than robotic group.
Conclusions: For most steps, ArtiSential performed as well as robotic and straight-shaped instruments. The development of specialized surgical techniques for ArtiSential will maximize the advantages of these instruments.

Keywords: Joints; Kidney; Laparoscopy; Robotics

INTRODUCTION

In urologic surgery, laparoscopic surgery is rapidly replacing open surgery due to its positive perioperative and oncologic outcomes, and surgical instruments are being developed accordingly. Some studies have reported that surgeons assuming a static posture for a long duration while performing laparoscopic surgery is associated with increased risk of developing musculoskeletal disorders [1] Currently, the fact that robotic surgery is more ergonomically favorable

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than laparoscopic surgery has promoted its further clinical use in many countries. Robotic systems improve visualization and provide enhanced manipulation of tissue via wrist-like movements of instruments [2]. Several studies have reported that robotic surgery offers outcomes comparable to or better than those of laparoscopic surgery in the urology field [3]. However, robotic surgery has several disadvantages. The robotic platform requires special devices and environmental factors; furthermore, it is devoid of touch sensation and incurs higher costs than other approaches [2,4,5].

ArtiSential (LIVSMED, Seongnam, Korea) was introduced as a new multi degree-of-freedom articulating laparoscopic instrument. It offers the advantage of the freedom of movement similar to robotic surgery and complements the disadvantages of conventional laparoscopic instruments in renal surgery [6]. ArtiSential eliminates the limitations of straight-shaped instruments and allows the wrist joint to be used freely over 360° as in robotic surgery. Few studies have reported on the usefulness of the articulating laparoscopic instrument in specified surgical fields [7,8]. In urology, few or no studies have evaluated this instrument in terms of its safety, usability, accuracy, and muscular stress on the surgeon [6]. Because clinical application in urologic surgery is relatively novel, we used a porcine model to compare the outcomes and surgical implications of renal surgery using the ArtiSential instruments with the da Vinci surgical system or a straight-shaped instrument.

MATERIALS AND METHODS

1. Animal care and study design

Our study protocol for performing animal experiments was approved by the Institutional Animal Care and Use Committee of Asan Institute for Life Sciences (no. 2021-12-113). Nine 4-week-old female Yorkshire pigs were acclimatized to our animal facility for two days before surgery. The pigs were equally divided into three groups: robotic, ArtiSential, and straight-shaped instrument groups. The median weight (interquartile range, IQR) of the pigs was 33.9 (33.3–35.0) kg. Female pigs were used to facilitate urethral catheterization during surgery. The pigs were fed a low-residue diet for 2 days before the surgical procedure. Pre-anesthesia medication comprised an intramuscular injection of alfaxane (1 mg/kg) plus azaperone (4 mg/kg) and xylazine HCl (1.2 mg/kg). Procedures were performed under general anesthesia (2%–3% isoflurane). Blood pressure, heart rate, respiration rate, and oxygen saturation were monitored during anesthesia. After all surgical procedures, all pigs were euthanized.

2. Surgical procedure

Pigs were positioned in a lateral decubitus position and prepared with routine surgical drapes using chlorhexidine gluconate. A Veress needle was used to achieve pneumoperitoneum with carbon dioxide. For contralateral renal surgery, the same pig was placed in the opposite lateral decubitus position, and pneumoperitoneum was once again established. Four ports were usually used in each surgical step. In the case of left-sided renal surgery, 0.8 to 1-cm camera port was positioned 4 cm left side-lateral to the midline on the left, 10 cm cranial to the umbilicus. The 0.8 to 1-cm working port was placed at a length of 15 cm from the bony prominence of external ilium, and a distance of 13 cm was maintained between the working port and last rib. The 0.8 to 1 cm back-hand port was placed at a distance of 15 cm from the angle of the last costovertebral joint. Finally, the 0.5-cm additional port was positioned approximately 18 cm lateral to the camera port. For the right-sided renal surgery, the ports were symmetrically positioned.

All renal surgeries were performed by a single surgeon (DY). The representative renal surgeries, including nephrectomy, partial nephrectomy, and nephroureterectomy with bladder cuffing, were subdivided into 10 detailed steps (Table 1). First, in kidney mobilization, the retroperitoneum was incised at the hilum, and the ventral aspect of the renal vasculature was exposed. Second, for renal pedicle dissection, the main renal vein and artery was clearly identified. For both vessels, all perivascular tissue was removed to minimize any loose tissue that could interfere with subsequent vascular clamping or ligation. Third, during renal pedicle clamping, the main renal artery and vein were clamped in turn using bulldog clamps. Fourth, tumor resection was performed by resecting a 1×1-cm^2 renal block of the lateral portion in middle pole. Fifth, renorrhaphy was performed using 3-0 absorbable sutures with a sliding-clip technique. The suture site was observed after de-clamping to determine whether additional stitching was needed for bleeding control. Sixth, the main renal vessel was ligated using medium-sized Hem-o-lok clips (Teleflex Medical, Durham, NC, USA). Seventh, the ipsilateral ureter was dissected to the entrance of the bladder. Eighth, the ureter was ligated using a medium-sized Hem-o-lok clip and excised. Ninth, for bladder cuff excision, a 4-French feeding tube was inserted into the remnant ureter, and the tip of the tube was placed in the bladder. Bladder cuff excision was achieved, including the intra-vesical ureteral orifice, along this tube. Finally, bladder repair was performed in a water-tight manner using 3-0 absorbable sutures, and then, bladder leak test was performed through a feeding tube for urethral catheterization.

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Table 1. Summary of surgical steps in renal surgery

10 surgical steps	Robotic group		ArtiSential group		Straight-shaped group	
	Left hand	Right hand	Left hand	Right hand	Left hand	Right hand
Kidney mobilization	Robotic Maryland bipolar forceps	Robotic Hot Shears™ (Intuitive Surgical Inc., Sunnyvale, CA, USA) (monopolar curved scissors)	AritiSential Maryland dissector	ArtiSential monopolar spatula	Laparoscopic dissector forceps	Laparoscopic monopolar hook
Renal pedicle dissection						
Renal pedicle clamping		Robotic ProGrasp™ forceps (Bulldog clamps)		Laparoscopic bulldog clip applying forceps (Aesculap® bulldog clips)		Laparoscopic bulldog clip applying forceps (Aesculap® bulldog clips)
Tumor resection		Robotic Hot Shears™ (monopolar curved scissors)		Laparoscopic scissors		Laparoscopic scissors
Renorrhaphy	Robotic large needle driver	Robotic Mega SutureCut™ needle driver		ArtiSential needle holder		Laparoscopic needle holder
Renal pedicle ligation	Robotic Maryland bipolar forceps	Robotic medium-large clip applier		ArtiSential medium-large clip applier		Laparoscopic medium-large clip applier
Ureter dissection		Robotic Hot Shears™ (monopolar curved scissors)		ArtiSential monopolar spatula		Laparoscopic monopolar hook
Ureter ligation		Robotic medium-large clip applier		ArtiSential medium-large clip applier		Laparoscopic medium-large clip applier
Bladder cuff excision		Robotic Hot Shears™ (monopolar curved scissors)		ArtiSential monopolar spatula		Laparoscopic monopolar hook
Bladder repair	Robotic large needle driver	Robotic Mega SutureCut™ needle driver		ArtiSential needle holder		Laparoscopic needle holder

In the robotic group, the surgeon totally used the robotic instruments (Maryland bipolar forceps, monopolar curved scissors, ProGrasp forceps, clip applier, and two needle drivers, including Mega SutureCut, Intuitive Surgical Inc., Sunnyvale, CA, USA). In the ArtiSential group, the surgeon used the articulating instruments (Maryland dissector, monopolar spatula, clip applier, and one needle holder), whereas in the straight-shaped instrument group, the surgeon used conventional laparoscopic instruments (monopolar hook, scissor, clip applier, and one needle holder). Owing to the absence of some ArtiSential instruments, in the ArtiSential group, the surgeon had to use laparoscopic bulldog clip applying forceps (Aesculap, Tuttlingen, Germany) for renal pedicle clamping and a conventional laparoscopic scissor for tumor resection as in the straight-shaped instrument group. The surgical devices used for each step are presented in Table 1.

3. Outcome measurements

Three groups were compared at each step-in terms of both objective and subjective parameters. Objective parameters included the operative time, blood loss, and intraoperative complications. The intraoperative complications related to each procedure were graded using the modified Satava classification system. Subjective parameters included usability of instrument as judged by the surgeon, accuracy of the procedure as judged by the reviewers, and musculoskeletal discomfort as judged by the surgeon. All reviewers reviewed the recorded videos during each surgical step and scored the accuracy of the procedure. The usability and accuracy of each procedure were evaluated using the 5-point Likert scale (5: excellent, 4: good, 3: fair, 2: poor, and 1: very poor). We evaluated the degree of surgeon's musculoskeletal discomfort experienced during the operation for each joint (hands, wrists, back, leg, elbows, shoulders, and neck) using a self-made scale. The degree of musculoskeletal discomfort was record using a 5-point scale (5: no pain, 4: weak pain, 3: moderate pain, 2: moderately strong pain, and 1: extremely strong pain).

4. Statistical analysis

Categorical variables were reported as number (%), and continuous variables were reported as the median (IQR). Comparisons were two-sided; a p-value less than 0.05 was considered statistically significant. Variables with skewed distributions were compared between two groups using the Mann–Whitney U-test, and variables with skewed distributions were compared among three groups using the Kruskal–Wallis test. All statistical analyses were performed using SPSS version 24.0 (IBM Corp., Armonk, NY, USA).

RESULTS

1. Animal data

The nine pigs successfully underwent renal surgeries without need for additional port placement or conversion to open surgery. Three pigs (six kidneys) underwent renal surgery in each group. Body and kidney weights did not significantly differ among the three groups. The body weight was 36.7 (32.7–37.7) kg in the robotic group, 33.8 (32.7–33.9) kg in the ArtiSential group, and 34.4 (33.5–34.5) kg in the straight-shaped instrument group (p=0.203). The kidney weight was 110.9 (95.8–121.9) g in the robotic group, 91.3 (81.8–108.0) g in the ArtiSential group, and 101.0 (95.5–13.1) g in the straight-shaped instrument group (p=0.134).

2. Objective parameters

Total median operative time (IQR) including all steps was 66.0 (61.7–75.6) min in the robotic group, 73.6 (64.6–88.8) min in the ArtiSential group, and 64.2 (61.1–67.6) min in the straight-shaped instrument group, showing no statistically significant difference (p=0.281). The median operative times for renal pedicle clamping and ureter dissection were significantly shorter in ArtiSential group than robotic group (1.3 min vs. 4.7 min, p=0.002; 8.1 min vs. 11.1 min, p=0.015). The median operative time for bladder cuff excision was longer in the ArtiSential group than the robotic group (12.4 min vs. 8.3 min, p=0.026). The median operative time for bladder repair was significantly longer in ArtiSential group than robotic and straight-shaped groups (17.9 min vs. 5.5 min, p=0.002 and 17.9 min vs. 9.3 min, p=0.026) (Table 2).

Total median blood loss for all steps was 14.6 (6.5–23.0) mL in the robotic group, 11.4 (8.1–23.8) mL in the Artisential group, and 14.2 (11.8–17.7) mL in the straight-shaped instrument group, showing no statistically significant difference (p=0.630). Even in each individual step of the renal surgery, there were no significant between-group differences in blood loss (Table 3). There were no statistically significant complications among the groups. In the robotic group, two intraoperative complications during renal pedicle dissection and ligation (one vein injury, grade I; one intestinal injury, grade II) occurred in two kidney units. The ArtiSential group had three intraoperative complications during kidney mobilization (one kidney parenchymal injury, grade I; two vascular injuries, grade II) in two kidney units. In the straight-shaped group, one ureteral injury (grade II) occurred during bladder cuff excision and one vascular injury (grade III) occurred during renal pedicle dissection.

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Table 2. Pairwise comparison of operative time (minute) among the three groups (robotic, ArtiSential, and straight-shaped)

Step for urology surgery	Robotics group			p-value	Artisential group			p-value	Straight-shaped group		
	Median	IQR			Median	IQR			Median	IQR	
		Q1	Q3			Q1	Q3			Q1	Q3
Kidney mobilization	8.9	7.0	11.7	0.394	12.1	7.2	13.9	0.650	7.1	6.1	9.1
Renal pedicle dissection	5.9	3.8	9.9	0.093	7.7	7.0	9.2	0.937	7.9	6.1	9.1
Renal pedicle clamping	4.7	3.8	7.5	0.002*	1.3	1.0	1.9	0.485	1.5	1.3	2.3
Tumor resection	4.0	3.4	5.8	0.240	3.2	2.6	4.3	0.093	4.7	3.8	5.4
Renorrhaphy	9.8	8.4	10.4	0.394	10.6	9.5	14.7	0.026*	8.0	7.0	9.9
Renal pedicle ligation	6.1	5.4	7.1	0.394	5.1	3.1	7.3	0.093	3.1	2.6	3.8
Ureter dissection	11.1	10.0	12.5	0.015*	8.1	4.3	9.8	0.937	7.7	7.4	8.6
Ureter ligation	1.8	1.0	2.8	0.310	1.1	0.9	1.3	>0.999	1.0	0.7	2.2
Bladder cuff excision	8.3	7.3	9.1	0.026*	12.4	8.7	15.1	0.699	10.3	8.6	12.8
Bladder repair	5.5	5.0	7.0	0.002*	17.9	10.5	19.6	0.026*	9.3	8.0	11.2

IQR, interquartile range; Q1, 25th percentile; Q3, 75th percentile.
*Statistically significant $p<0.05$.

Table 3. Pairwise comparison of blood loss (mL) among the three groups (robotic, ArtiSential, and straight-shaped)

Step for urology surgery	Robotics group			p-value	Artisential group			p-value	Straight-shaped group		
	Median	IQR			Median	IQR			Median	IQR	
		Q1	Q3			Q1	Q3			Q1	Q3
Kidney mobilization	1.67	0.51	3.09	0.937	1.15	0.73	9.03	>0.999	1.30	0.78	3.80
Renal pedicle dissection	1.25	0.41	3.65	0.240	0.17	0.14	2.79	0.485	0.90	0.49	1.00
Renal pedicle clamping	0.45	0.24	0.59	0.394	0.08	0.06	1.57	0.394	0.26	0.12	0.41
Tumor resection	2.43	0.59	4.76	0.818	3.05	1.25	3.66	0.937	2.98	2.13	3.57
Renorrhaphy	1.04	0.46	1.85	0.310	1.22	0.99	2.99	0.818	1.54	0.85	2.70
Renal pedicle ligation	0.53	0.24	0.62	0.937	0.35	0.23	0.66	0.699	0.25	0.13	0.86
Ureter dissection	1.57	0.68	2.71	0.394	0.86	0.38	2.57	0.394	1.51	0.71	3.08
Ureter ligation	0.46	0.35	0.95	0.093	0.19	0.13	0.61	0.937	0.21	0.12	1.07
Bladder cuff excision	2.08	0.77	3.13	0.394	1.31	0.76	4.06	0.589	1.08	0.24	2.46
Bladder repair	1.26	0.79	2.59	>0.999	1.76	0.30	3.42	0.818	2.04	1.21	3.29

IQR, interquartile range; Q1, 25th percentile; Q3, 75th percentile.

3. Subjective parameters in each surgical step

The ArtiSential device was less useful than the da Vinci surgical system (Intuitive Surgical Inc.) for renorrhaphy (p=0.01) and bladder repair (p<0.01). The usability did not significantly differ between the ArtiSential group and the straight-shaped instrument group for any surgical step (Table 4).

Compared to the robotic group, the ArtiSential group was more accurate for renal pedicle dissection but less accurate than the robotic group for tumor resection, renorrhaphy, and bladder repair. Compared to the straight-shaped instrument group, the ArtiSential group was more accurate for bladder cuff excision but less accurate for bladder repair (Table 5).

The surgeon experienced more hand discomfort during ureter dissection in the ArtiSential group than in the robotic group (Table 6). The surgeon experienced more wrist discomfort during ureter dissection, bladder cuff excision, and bladder repair in the ArtiSential group than in the robotic group (Table 7), but the surgeon reported less back discomfort in the former than in the latter (Table 8). The stress caused to the surgeon's legs, elbows, shoulders, and the neck did not significantly differ among the three groups (Supplementary Tables 1–4).

DISCUSSION

We are living in an era of minimally invasive surgery. Since the introduction of such surgeries, there has been tremendous development in laparoscopic instruments including the robotic system. Several studies have suggested that laparoscopic surgery is non-inferior to robotic surgery in clinical feasibility [3,4,9-12]. In the present study, we confirmed that the ArtiSential devices, which were developed to enable the wrist joint to be used freely over 360°, have comparable usability and accuracy to conventional laparoscopic instruments or robotic arm in renal surgery. The objective parameters like the operative time or subjective parameters like usability did not significantly differ between groups in almost surgical steps without need for suturing. Interestingly, for the step of ureter dissection, ArtiSential surgery had a benefit of a shorter operative time than robotic surgery, and the joint fatigue was similar for ArtiSential device and conventional laparoscopic instruments. However, back stress was lower in ArtiSential surgery than in robotic surgery.

In this study, we experienced that during the bladder repair step, which requires suturing in a narrow space, such as the pelvic cavity, the operator took less time when using a thin conventional laparoscopic instrument or a robotic

Table 4. Pairwise comparison of usability among the three groups (robotic, ArtiSential, and straight-shaped)

Step for urology surgery	Robotics group			p-value	Artisential group			p-value	Straight-shaped group		
	Median	IQR			Median	IQR			Median	IQR	
		Q1	Q3			Q1	Q3			Q1	Q3
Kidney mobilization	4.50	4.00	5.00	0.818	4.50	3.75	5.00	>0.999	4.50	3.75	5.00
Renal pedicle dissection	5.00	4.75	5.00	0.699	5.00	4.00	5.00	>0.999	5.00	4.00	5.00
Renal pedicle clamping	5.00	4.00	5.00	0.394	5.00	5.00	5.00	0.699	5.00	4.75	5.00
Tumor resection	5.00	4.75	5.00	>0.999	5.00	4.75	5.00	>0.999	5.00	4.75	5.00
Renorrhaphy	5.00	4.75	5.00	0.009*	4.00	2.50	4.00	0.699	4.00	3.00	4.25
Renal pedicle ligation	5.00	5.00	5.00	0.394	5.00	4.00	5.00	0.394	5.00	5.00	5.00
Ureter dissection	4.00	4.00	5.00	0.180	5.00	4.75	5.00	0.394	4.50	4.00	5.00
Ureter ligation	5.00	5.00	5.00	>0.999	5.00	5.00	5.00	>0.999	5.00	5.00	5.00
Bladder cuff excision	5.00	5.00	5.00	0.394	4.00	3.75	4.25	0.132	5.00	4.00	5.00
Bladder repair	5.00	5.00	5.00	0.002*	3.50	2.00	4.00	0.485	4.00	3.00	4.00

IQR, interquartile range; Q1, 25th percentile; Q3, 75th percentile.
*Statistically significant p<0.05.

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Table 5. Pairwise comparison of accuracy among the three groups (robotic, ArtiSential, and straight-shaped)

Step for urology surgery	Robotics group			p-value	Artisential group			p-value	Straight-shaped group		
	Median	IQR			Median	IQR			Median	IQR	
		Q1	Q3			Q1	Q3			Q1	Q3
Kidney mobilization	5.00	4.25	5.00	0.101	4.00	3.25	5.00	0.178	5.00	4.00	5.00
Renal pedicle dissection	4.00	4.00	5.00	0.039*	5.00	5.00	5.00	0.487	5.00	4.25	5.00
Renal pedicle clamping	5.00	4.00	5.00	0.291	5.00	5.00	5.00	0.478	5.00	4.25	5.00
Tumor resection	5.00	5.00	5.00	0.002*	4.00	3.25	4.00	0.291	4.00	3.00	4.00
Renorrhaphy	4.50	4.00	5.00	0.024*	4.00	3.00	4.00	0.089	4.00	4.00	4.00
Renal pedicle ligation	5.00	5.00	5.00	0.242	5.00	3.25	5.00	0.671	5.00	4.00	5.00
Ureter dissection	5.00	4.00	5.00	0.755	5.00	4.25	5.00	0.755	5.00	4.00	5.00
Ureter ligation	5.00	4.00	5.00	0.755	5.00	4.00	5.00	0.514	5.00	4.25	5.00
Bladder cuff excision	5.00	4.25	5.00	0.713	5.00	4.00	5.00	0.005*	3.00	2.25	4.00
Bladder repair	5.00	5.00	5.00	<0.001*	2.50	2.00	3.75	0.005*	4.00	3.25	4.00

IQR, interquartile range; Q1, 25th percentile; Q3, 75th percentile.
*Statistically significant p<0.05.

Table 6. Pairwise comparison of hand discomfort among the three groups (robotic, ArtiSential, and straight-shaped)

Step for urology surgery	Robotics group			p-value	Artisential group			p-value	Straight-shaped group		
	Median	IQR			Median	IQR			Median	IQR	
		Q1	Q3			Q1	Q3			Q1	Q3
Kidney mobilization	5.00	5.00	5.00	>0.999	5.00	5.00	5.00	0.394	5.00	3.75	5.00
Renal pedicle dissection	5.00	5.00	5.00	>0.999	5.00	5.00	5.00	0.394	5.00	4.00	5.00
Renal pedicle clamping	5.00	5.00	5.00	>0.999	5.00	5.00	5.00	0.394	5.00	4.00	5.00
Tumor resection	5.00	5.00	5.00	>0.999	5.00	5.00	5.00	0.394	5.00	4.00	5.00
Renorrhaphy	5.00	5.00	5.00	0.394	5.00	4.00	5.00	0.132	4.00	3.75	4.25
Renal pedicle ligation	5.00	5.00	5.00	>0.999	5.00	5.00	5.00	0.699	5.00	4.75	5.00
Ureter dissection	5.00	5.00	5.00	0.699	5.00	4.75	5.00	0.065	4.00	4.00	4.25
Ureter ligation	5.00	5.00	5.00	>0.999	5.00	5.00	5.00	0.394	5.00	4.00	5.00
Bladder cuff excision	5.00	5.00	5.00	0.065	4.00	3.75	5.00	0.699	4.00	3.75	4.25
Bladder repair	5.00	5.00	5.00	0.002*	3.50	3.00	4.00	0.180	4.00	4.00	4.00

IQR, interquartile range; Q1, 25th percentile; Q3, 75th percentile.
*Statistically significant p<0.05.

Table 7. Pairwise comparison of wrist discomfort among the three groups (robotic, ArtiSential, and straight-shaped)

Step for urology surgery	Robotics group			p-value	Artisential group			p-value	Straight-shaped group		
	Median	IQR			Median	IQR			Median	IQR	
		Q1	Q3			Q1	Q3			Q1	Q3
Kidney mobilization	5.00	5.00	5.00	0.394	5.00	4.00	5.00	0.699	5.00	4.75	5.00
Renal pedicle dissection	5.00	4.75	5.00	0.699	5.00	5.00	5.00	>0.999	5.00	5.00	5.00
Renal pedicle clamping	5.00	5.00	5.00	>0.999	5.00	5.00	5.00	>0.999	5.00	5.00	5.00
Tumor resection	5.00	5.00	5.00	0.699	5.00	4.75	5.00	0.699	5.00	4.00	5.00
Renorrhaphy	5.00	5.00	5.00	0.065	4.00	3.00	5.00	0.818	4.00	4.00	4.25
Renal pedicle ligation	5.00	5.00	5.00	0.065	4.00	4.00	5.00	0.394	5.00	4.00	5.00
Ureter dissection	5.00	5.00	5.00	0.015*	4.00	4.00	4.25	0.394	4.50	4.00	5.00
Ureter ligation	5.00	5.00	5.00	0.180	4.50	4.00	5.00	0.394	5.00	4.75	5.00
Bladder cuff excision	5.00	5.00	5.00	0.002*	4.00	3.75	4.00	0.394	4.00	4.00	4.25
Bladder repair	5.00	5.00	5.00	0.002*	4.00	2.75	4.00	0.394	4.00	3.75	4.25

IQR, interquartile range; Q1, 25th percentile; Q3, 75th percentile.
*Statistically significant $p<0.05$.

Table 8. Pairwise comparison of back discomfort among the three groups (robotic, ArtiSential, and straight-shaped)

Step for urology surgery	Robotics group			p-value	Artisential group			p-value	Straight-shaped group		
	Median	IQR			Median	IQR			Median	IQR	
		Q1	Q3			Q1	Q3			Q1	Q3
Kidney mobilization	4.50	3.75	5.00	0.180	5.00	5.00	5.00	>0.999	5.00	5.00	5.00
Renal pedicle dissection	4.50	3.75	5.00	0.180	5.00	5.00	5.00	>0.999	5.00	5.00	5.00
Renal pedicle clamping	4.50	3.75	5.00	0.180	5.00	5.00	5.00	>0.999	5.00	5.00	5.00
Tumor resection	5.00	3.75	5.00	0.394	5.00	5.00	5.00	>0.999	5.00	5.00	5.00
Renorrhaphy	5.00	4.75	5.00	0.065	5.00	5.00	5.00	0.699	5.00	4.75	5.00
Renal pedicle ligation	4.00	4.00	4.25	0.015*	5.00	5.00	5.00	>0.999	5.00	5.00	5.00
Ureter dissection	4.00	3.75	4.25	0.015*	5.00	5.00	5.00	>0.999	5.00	5.00	5.00
Ureter ligation	4.50	3.75	5.00	0.180	5.00	5.00	5.00	>0.999	5.00	5.00	5.00
Bladder cuff excision	4.00	4.00	4.00	0.002*	5.00	5.00	5.00	>0.999	5.00	5.00	5.00
Bladder repair	4.00	3.75	4.00	0.002*	5.00	5.00	5.00	0.699	5.00	4.75	5.00

IQR, interquartile range; Q1, 25th percentile; Q3, 75th percentile.

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arm with a small range of joint movement than when using the ArtiSential device [13]. Meanwhile, during the ureter dissection step, wherein the operator's view moved more frequently for a wide surgical field, the ArtiSential surgery required significantly less operative time than robotic surgery. Blood loss volume and intraoperative complications did not significantly differ among the three groups in the present study. In previous studies, the use of a robotic system in radical nephrectomy was not associated with a risk of increased blood loss when compared with laparoscopic renal surgery. In addition, regarding intraoperative complications in renal surgeries like radical nephrectomy, partial nephrectomy, and nephroureterectomy with bladder cuff excision, the robotic system was not inferior to laparoscopic surgery in terms of patient safety [9,11,12]. In the present study, our robotic group had a case of bowel injury due to the poor haptic sense of the robot arm during insertion. In addition, in one case of conventional laparoscopic surgery, the surgeon cauterized the main artery erroneously because of unclear exposure of the surgical site due to insufficient angulation of the straight-shaped instrument. The authors expect the ArtiSential device to help address these limitations of the other instruments because of the alerts for haptic sense to the surgeon and free articulation of the instrument tip [7,8].

In our study, the ArtiSential was less useable and less accurate than robotic system for renorrhaphy and bladder repair. In a conventional laparoscopic setting, normal and comfortable suturing comprises parallel placement of the needle holder and the suture site. Occasionally, the tissue can be pulled or pushed to make this angle [14]. The usefulness of suturing in robotic surgery can be attributed to advantages of the robot arm providing enhanced manipulation of tissue via the wrist-like movements of all the instruments [2,15]. In addition, the robotic system can approach the surgical site at a comfortable angle with little manipulation [15,16]. And the robotic system had a fourth arm that maintained the ideal suture angle during the operation, and the operator had the advantage of performing suturing with only simple wrist movements [10,17,18]. The effective use of the fourth arm enabled the surgeon to locate the ideal surgical position without surgical site assistants' support [19,20]. In the ArtiSential group, the operator needed to use more force when using the needle holder because of the head weight of the device, which could limit the allowed joint range [21,22]. In addition, the ArtiSential needle holder did not have a locking function while holding the needle, which places a lot of strain on the operator's fingers.

One previous study showed that a greater number of muscle groups are activated during laparoscopic surgery than during robotic surgery, suggesting an ergonomic benefit of the latter over the former [23]. In our study, the musculoskeletal stress caused by ArtiSential was equivalent to that caused by straight-shaped instrument. Interestingly, we expected the ArtiSential group to have lesser wrist discomfort due to usability of the wrist joint, but conversely, the ArtiSential group was associated with greater wrist discomfort for the surgeon compared with the robotic system during bladder cuff excision and bladder repair. This was particularly true when a lot of manipulation was required within a narrow surgical field, such as during bladder cuff excision and bladder repair. The relatively heavy ArtiSential device is mostly supported by the operator's wrist, and when suturing and fine dissection are required, the stress on the wrist could be significant [21,22]. It is necessary to reduce the weight of the ArtiSential instrument and improve the instrument so that it can be suitable for suturing and precise movements. Efforts have been made to distribute wrist force in the previously developed "limited articulated laparoscopic device" and clinical safety and feasibility comparable to the robotic system have been reported in surgery with suturing [6,24,25].

This study has some limitations. First, because porcine anatomies are different from those of humans, our experimental results may not be directly applicable to humans and cannot fully predict clinical outcomes [26]. Second, judging from our experience, performing the operation with the conventional surgical method in the new multi-articulating laparoscopic device can have a negative effect on the results. Further investigation is needed to evaluate whether there is a substantial learning curve for renal surgery with articulating instrumentation. Third, considering the clinical application for future studies, the ArtiSential instruments needs to be further improved to promote its usability, and specialized surgical techniques must be designed for these instruments. To our knowledge, this study is the first to evaluate multi degree-of-freedom articulating laparoscopic instrument in the field of urologic surgery. Our study was evaluated a medical device before first-in-human studies as the idea, development, exploration, assessment, and long-term follow-up (IDEAL) stage 0. We are performing human subjective study in urologic field to develop and explore feasible instruments and suitable surgical techniques in this regard.

CONCLUSIONS

ArtiSential is comparable to the da Vinci surgical system or straight-shaped instruments for most steps in terms of objective and subjective parameters. The ArtiSential instrument for suturing needs to be further improved to promote its usability. In addition, the development of specialized surgical techniques for ArtiSential will maximize the advantages of this new instrument.

CONFLICTS OF INTEREST

The authors have nothing to disclose.

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AUTHORS' CONTRIBUTIONS

Research conception and design: Dalsan You, Jong Keun Kim, and Donghwan Bae. Data acquisition: Jong Keun Kim, Bosik Kang, and Myoung Jin Jang. Data analysis and interpretation: Dalsan You, Jong Keun Kim, Yu Seon Kim, and Yujin Yun. Drafting of the manuscript: Dalsan You and Jong Keun Kim. Obtaining funding: Dalsan You. Supervision: Dalsan You and Jong Keun Kim. Approval of the final manuscript: all authors.

SUPPLEMENTARY MATERIALS

Supplementary materials can be found via https://doi.org/10.4111/icu.20220182.

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