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ORIGINAL ARTICLE – ENDOCRINE TUMORS

Robotic Adrenalectomy Using the da Vinci SP Robotic System: Technical Feasibility Comparison with Single-Port Access Using the da Vinci Multi-arm Robotic System

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ABSTRACT

Background. Laparoscopic adrenalectomy is the gold standard for adrenal tumor; however, robotic adrenal surgery has gained interest recently. For minimally invasive surgeries, we first reported on robotic adrenalectomy using a single-port access performed using the da Vinci multi-arm robotic system (RA-SA) in 2011. Since its introduction in 2018, we first performed robotic adrenalectomy using the da Vinci SP robotic system in 2020.

Objective. We aimed to introduce the novel single-port robotic system (RA-SP) for adrenalectomy and evaluate its technical feasibility by comparing it with the surgical outcomes of patients who underwent robotic adrenalectomy using the RA-SA.

Methods. Eight patients who underwent robotic adrenalectomy using the RA-SP from February 2020 to June 2021 were compared with 11 patients who underwent RA-SA from 2011 to 2015 by a single surgeon.

Results. The two groups were similar in age, sex, body mass index, type of operation, and final pathologic diagnosis. Despite no significant differences, RA-SP resulted in moderately less mean operation time, estimated blood loss, and length of hospitalization.

Conclusions. The Da Vinci SP robotic system is a novel, safe, and feasible technique to improve the convenience of operation and cosmetic effect for adrenalectomy.

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Since 1992, laparoscopic adrenalectomy (LA) has commonly been performed for adrenal tumor.[1] Despite being the gold standard, several minimally invasive approaches are still being attempted. Compared with laparoscopic transperitoneal adrenalectomy (LTA), researchers introduced posterior retroperitoneoscopic adrenalectomy (PRA), which provided direct access to the retroperitoneal space to prevent intra-abdominal adhesions. Moreover, it reduced the mean operative time, average oral intake time, mean hospitalization, and postoperative pain.[2–5] Since the development of surgical technology for robotic systems, robotic adrenalectomy (RA) has been introduced in numerous ways, ranging from LTA to PRA, and from multiport to single-port access.[6–9] Furthermore, according to Brandao et al., RA can be performed safely and effectively with operative time and provides potential advantages of a shorter hospitalization, less blood loss, and lower occurrence of postoperative complications.[10] There are reports on LA being better than RA when considering tumor size, location, patient's body mass index (BMI), and the learning curve for surgeons. Nonetheless, a three-dimensional (3D) working field with a magnified view, and tremor-filtering multi-articulated instruments of the robotic system, can permit meticulous manipulation of adrenal tissue with minimally invasive surgery.[11–13]

Previously published studies on RA were based on a single-port access, however these studies used the da Vinci Si or Xi robotic system (Intuitive Surgical, Sunnyvale, CA, USA), which has separate multi-arms.[14,15] The recently

developed da Vinci SP robotic system (Intuitive Surgical, Sunnyvale, CA, USA) allows single-port access through a single 2.5 cm cannula. It has a single arm that delivers three multi-jointed instruments and a completely wristed 3D high-definition (HD) camera for visibility and control in a narrow working space. All SP robotic system instruments can have a similar degree of movement and freedom as the Si or Xi robotic system. Our institution first introduced this robotic system in 2018, and eight cases of RA have been performed using the da Vinci SP robotic system (RA-SP). This is the first report on the methods and preliminary results of RA-SP, in comparison with adrenalectomy using the da Vinci Si or Xi robotic system with single-port access (RA-SA).

METHODS

Patients

We evaluated eight Asian patients who underwent RA-SP performed by a surgeon at the Severance Hospital, Yonsei University College of Medicine, Seoul, Korea, between February 2020 and June 2021. To evaluate the feasibility of the RA-SP, we compared these patients with 11 Asian patients who underwent RA-SA from 2011 to 2015 performed by similar surgeons. Patient selection from an outpatient clinic included the size of the adrenal tumor (<4 cm), BMI <30 kg/m^2, and patient preference for RA. However, there were two exceptional cases of tumor size in the RA-SA group. One was a 25-year-old woman diagnosed with a 7.0 cm adrenal incidentaloma, who wanted to undergo RA-SA because of the cosmetic effect, and the other was a 51-year-old woman diagnosed with a 4.5 cm primary hyperaldosteronism of the left adrenal gland and with a BMI of 24.5, who underwent RA on the recommendation of the surgeon. We collected the clinical and pathological data retrospectively and stored the data in a dedicated database for analysis. This study was conducted in accordance with the tenets of the Declaration of Helsinki (as revised in 2013) and was approved by the Yonsei University Institutional Review Board (IRB No: 4-2021-0667). The need for informed consent was waived owing to the retrospective design of this study.

Operative Procedures

Of the eight patients who underwent RA-SP, one patient had a tumor size of 3.7 cm and was subjected to the transperitoneal approach (TPA); the remaining seven patients underwent PRA. For robotic PRA using the da Vinci SP robotic system, patients were placed in a prone jackknife position with their hip joints bent and fixed at a right angle, as in LA. Soft pillows and pads were applied at the weight-bearing and bony prominent area to avoid direct pressure. Some space was required under the belly for pushing the intraperitoneal organs by the pneumoretroperitoneum (Fig. 1). At this position, exposure of the area between the lower rib and pelvic bone could be optimized for introducing the trocar. A 3 cm transverse skin incision was made below the lowest tip of the 12th rib, which avoided injuring the paraspinal muscles (Fig. 2). Following skin incision, the retroperitoneal space could be reached by passing through the three layers of the abdominal wall muscles, and a small space was created through the blunt dissection using the index finger. Subsequently, the glove port (Nelis, Kyung-gi, Korea) was placed through the skin incision and CO_2 gas was insufflated up to 18 mmHg for the pneumoretroperitoneum. The camera was inserted in the top lumen, and Maryland bipolar forceps were inserted in both lateral lumens. The Cardiere forcep for traction is usually introduced on the bottom lumen. The camera and Cardiere forcep lumens could be exchanged by rotating the cannula by 180°, according to the procedural steps. Following port placement with gas, the instrument arm was placed with the matched axis, with an appropriate aim to the target organ (Fig. 3). Consequently, the cannula was attached to the arm port and introduced to the transparent uniport. Simultaneously, the remote center of the cannula was placed at least 5 cm apart from the skin incision, because the endo-wrists of the robotic instrument could be activated on the points 5-cm apart from the tip of cannula. An assist port was used for the suction of fumes, irrigation, and traction (Fig. 4). Following robot docking, the subsequent surgical procedure was similar to other RAs using the Si or Xi robotic system. Intraoperative video recordings of patients are attached (Videos 1 and 2). Robotic TPA and RA-SA were performed in a similar manner as previously described.[7,16]

Statistical Analyses

All statistical analyses were performed using the Statistical Package for the Social Sciences for Windows software version 24.0 (IBM Corporation, Armonk, NY, USA). Continuous quantitative data are expressed as means ± standard deviations (SDs), while categorical qualitative data are expressed as percentages. We compared data from the two patient groups using the Chi-square test or Mann–Whitney U test, as appropriate. All p values < 0.05 were considered statistically significant.

FIG. 1 Position of the patient during the operation

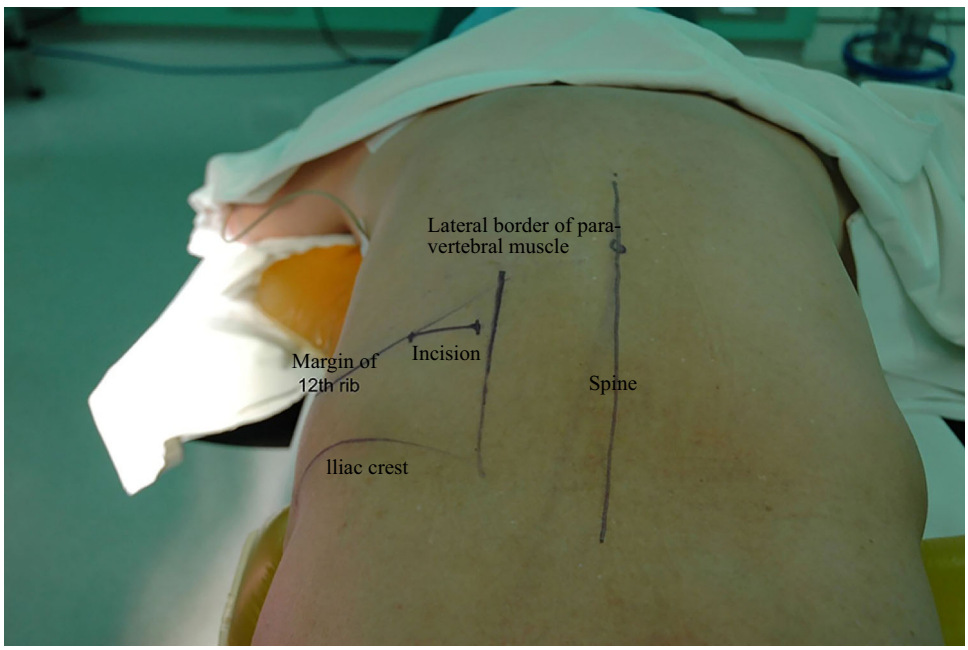

FIG. 2 Marking of the skin for the incision site

RESULTS

Baseline Clinical Characteristics and Diagnosis

There were no significant differences in patient demographics, including sex, age, body BMI, and abdominal operation history, between the groups. The proportion of men and women was 4:4 and 4:7 in the RA-SP and RA-SA groups, respectively ($p = 0.552$). The mean age was 40.1 ± 9.8 years (range 27–58) and 43.9 ± 11.8 years (range 25–62) in the RA-SP and RA-SA groups, respectively ($p = 0.322$), while BMI was 24.8 ± 3.1 (range 19.5–28.3) in the RA-SP group and 22.2 ± 1.8 (range 18.7–24.5) in the RA-SA group ($p = 0.392$). Two patients (25.0%) in the RA-SP group underwent abdominal operation, such as cholecystectomy and appendectomy. In contrast, three patients (27.2%) in the RA-SA group underwent intra-abdominal myomectomy, endometriosis operation, and cesarean section ($p = 0.912$). Adrenal tumor characteristics included primary hyperaldosteronism, pheochromocytoma, Cushing's syndrome, aldosterone-cortisol co-producing adenoma, and incidentaloma, with each accounting for 75.0%, 0.0%, 0.0%, 12.5%, and 12.5% in the RA-SP group, and 63.6%, 18.2%, 9.1%, 0.0%, and 9.1% in the RA-SA group, respectively ($p = 0.449$) (Table 1).

Surgical Outcomes

Table 2 summarizes the operation type and surgical outcomes between the groups. While seven patients (87.5%) who underwent RA-SP proceeded with the PRA, one patient (12.5%) who underwent RA-SP proceeded with the lateral TPA. All patients in the RA-SA group underwent PRA, and there was no significant difference between the groups ($p = 0.228$). Right- and left-side approaches were used in three and five patients in the RA-SP group, respectively, and three and eight patients in the RA-SA

FIG. 3 Docking process

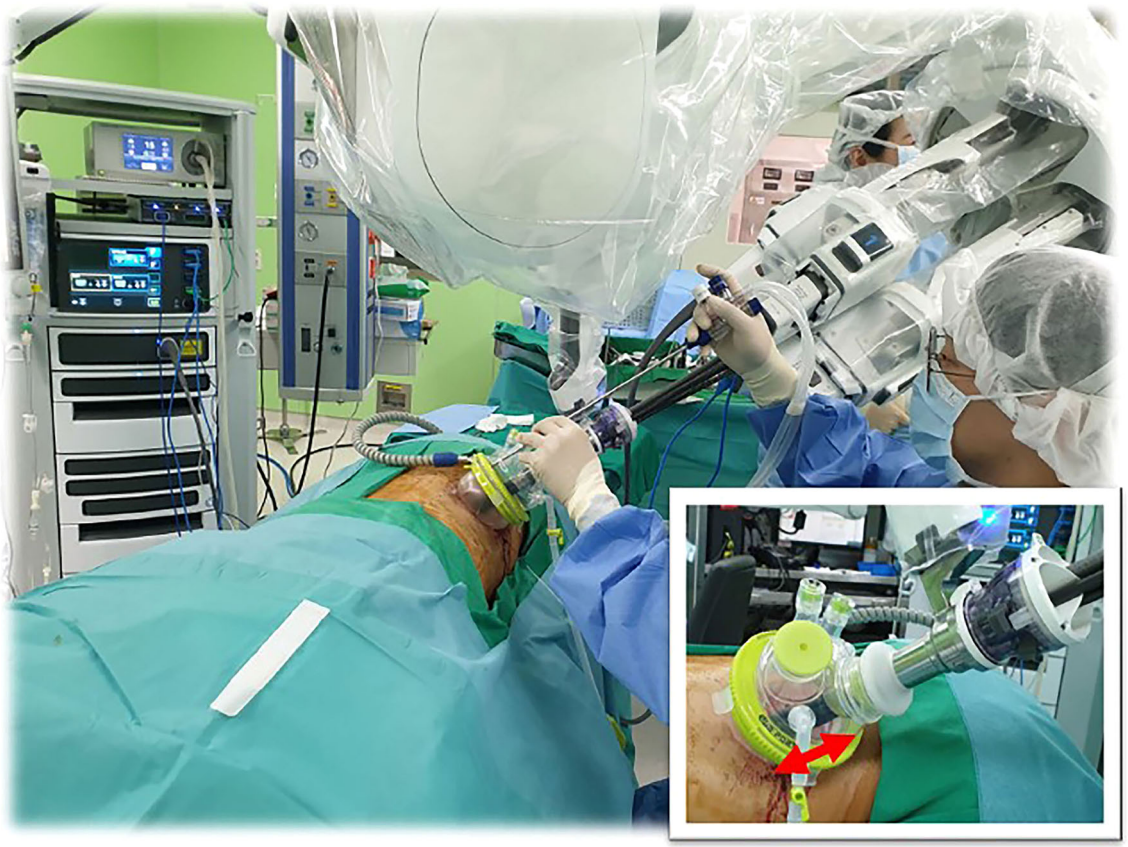

FIG. 4 Position of the robotic system during the operation

TABLE 1 Comparison of the baseline clinical characteristics and diagnosis between the two surgical methods

Variable	RA-SP [n = 8]	RA-SA [n = 11]	p value
Sex, male:female	4:4	4:7	0.552
Age, years	40.1 ± 9.8 (27–58)	43.9 ± 11.8 (25–62)	0.322
BMI, kg/m^2	24.8 ± 3.1 (19.5–28.3)	22.2 ± 1.8 (18.7–24.5)	0.392
Abdominal operation hx	2 (25.0)	3 (27.2)	0.912
Preoperative diagnosis			
Primary hyperaldosteronism	6 (75.0)	7 (63.6)	0.449
Pheochromocytoma	0 (0.0)	2 (18.2)	
Cushing's syndrome	0 (0.0)	1 (9.1)	
Aldosterone-cortisol co-producing adenoma	1 (12.5)	0 (0.0)	
Incidentaloma	1 (12.5)	1 (9.1)	

Data are expressed as number of patients (%) or mean ± SD (range)

Statistically significant differences were defined as $p < 0.05$

RA-SP robotic adrenalectomy using the da Vinci SP surgical robotic system, *RA-SA* robotic adrenalectomy using the da Vinci Si or Xi surgical robotic system with single-port access, *BMI* body mass index, *hx* history, *SD* standard deviation

TABLE 2 comparison of surgical outcomes between the two surgical methods

Variable	RA-SP[n = 8]	RA-SA [n = 11]	p value
Approach method, TPA:PRA	1:7	0:11	0.228
Operation site, right:left	3:5	3:8	0.636
Tumor size, cm	1.7 ± 1.0 (0.5–3.7)	2.3 ± 1.9 (1.0–7.0)	0.514
Laparoscopic conversion	0 (0.0)	2 (18.2)	0.202
Total operation time, min	99.0 ± 16.2 (81–119)	121.9 ± 50.7 (78–235)	0.434
Docking time, min[a]	4.8 ± 2.4 (2–10)	7.7 ± 4.4 (3–17)	0.409
Console time, min[b]	57.1 ± 15.2 (38–80)	49.1 ± 10.6 (36–63)	0.379
Estimated blood loss, mL	2.5 ± 4.6	17.3 ± 18.5	0.255
Complications	0	0	
Length of hospital stay, days	2.5 ± 0.5 (2–3)	3.4 ± 1.1 (2–6)	0.220

Data are expressed as number of patients (%) or mean ± SD (range)

Statistically significant differences were defined as $p < 0.05$

RA-SP robotic adrenalectomy using the da Vinci SP surgical robotic system, *RA-SA* robotic adrenalectomy using the da Vinci Si or Xi surgical robotic system with single-port access, *TPA* transperitoneal adrenalectomy, *PRA* posterior retroperitoneoscopic adrenalectomy, *SD* standard deviation

[a]Docking time of RA-SA included nine patients who completed the whole surgical procedure using a robotic system

[b]Console time of RA-SA included nine patients who completed the whole surgical procedure using a robotic system

group, respectively (p = 0.636). Tumor size was 1.7 ± 1.0 (range 0.5–3.7) and 2.3 ± 1.9 (range 1.0–7.0) in the RA-SP and RA-SA groups, respectively (p = 0.514). The final pathology after surgery showed that 9 of 11 patients in the RA-SA group had completely excised adrenal cortical adenoma. Of the remaining two patients diagnosed with pheochromocytoma before surgery, one was diagnosed with a low risk of malignancy of a 1.4 cm pheochromocytoma and the other was diagnosed with a 7 cm ganglioma. Six of eight patients in the RA-SP group were diagnosed with completely excised adrenal cortical adenoma, while the remaining two patients were diagnosed with multiple adrenal cortical adenomas, composed of a large nodule of 1.2 cm, and a 3.7 cm lymphangioma. There were no conversion cases for RA-SP; however, two cases (18.2%) of RA-SA could not complete the entire procedure using the robotic system and therefore converted to a laparoscopic operation (p = 0.202). The mean operation time in the RA-SP group was 99.0 ± 16.2 min (range 81–119), including 4.8 ± 2.4 min (range 2–10) and 57.1 ± 15.2 min (range 38–80) of docking and console time, respectively, compared with 121.9 ± 50.7 min

(range 78–235) in the RA-SA group, including 7.7 ± 4.4 min (range 3–17) and 49.1 ± 10.6 min (range 36–63) of docking and console time, respectively. The mean operation time in the RA-SA group included all 11 patients. Moreover, we averaged the docking and console times for nine patients, except for two cases of laparoscopic conversion, and these were statistically indifferent ($p = 0.434$, $p = 0.409$, and $p = 0.379$, respectively). The mean estimated blood loss was 2.5 ± 4.6 mL and 17.3 ± 18.5 mL in the RA-SP and RA-SA groups, respectively, without a statistically significant difference ($p = 0.255$). In the two groups, there were no surgical complications. In addition, the length of hospitalization was 2.5 ± 0.5 days (range 2–3) and 3.4 ± 1.1 days (range 2–6) in the RA-SP and RA-SA groups, respectively ($p = 0.220$).

DISCUSSION

Researchers have recently diversified surgical methods because of their continuous interest in minimally invasive surgery.[6] The development of surgical technology has resulted in the production of novel surgical instruments and equipment, in line with these changes. Since White et al. performed robotic laparo-endoscopic single-site radical prostatectomy using the da Vinci robotic system in 2009, various studies have reported on robotic single-site surgery (RSSS).[17–20] In the case of adrenal surgery, RSSS was first performed at our institution in 2010.[7] Since then, reports have been published on the safety and feasibility of RSS adrenalectomy.[8,15] Until 2019, all robotic surgeries were based on a multi-arm robotic surgical system. Approved by the US FDA in 2018, the da Vinci SP robotic system was introduced at our institution in late 2018. By applying this robotic system to adrenalectomy, the first surgery was performed in February 2020. Consequently, a total of eight patients were operated by one surgeon until June 2021. This novel system uses a 2.5 cm cannula to introduce three multi-jointed instruments and a wristed 3D HD camera on independent drives. The difference compared with the multi-arm robotic system is that on rotating the wrist of each arm in the multi-arm robotic system, the SP robotic system can move up to the wrist and elbow in the operation field (Video 2). The three instruments and camera facilitate an excellent internal range of motion, angulated around the target organ with visualization of blind spots. Moreover, they provide meticulous movements and prevent the assistant's manipulation restrictions from the outside, owing to the motion of the robot's multi-arms. However, the system is disadvantageous in that there is no energy device, such as an harmonic scalpel, and it only enables coagulation using monopolar electrocautery and Erbe (Erbe USA, Marietta, GA, USA). Thus, reliable hemostasis may be inconvenient. This necessitates ensuring an accurate dissection to prevent bleeding, and appropriately clipping the major vessels. In addition, the diameter of instruments is 5 mm; hence, the operating force is relatively weak compared with the multi-arm robotic system using 7 mm instruments. Furthermore, it may be inconvenient to manipulate the hard fat tissue around the adrenal gland and the large adrenal tumor.

Considering the study as an introduction to RA-SP, the procedure was principally performed with a small-sized adrenal tumor (range 0.5–3.7 cm). In the case of the RA-SA group, the surgery was performed on large tumors up to 7.0 cm. Primary hyperaldosteronism was the most common tumor in the RA-SP (75%) and RA-SA (63.6%) groups; however, there were two cases (18.2%) of pheochromocytoma in the RA-SA group. All patients in the RA-SA groups underwent PRA; however, only one patient in the RA-SP group underwent PRA, with a 5-mm additional port insertion for liver traction. This 28-year-old woman was diagnosed with a 3.7 cm adrenal incidentaloma and had a history of unknown surgery for flank pain in kindergarten. We decided to perform TPA because of concerns about adhesion considering the patient's surgical history.

Mercan et al. first reported on the technique of PRA in 1995,[21] following which Walz el al. standardized the procedure.[22] PRA reduces estimated blood loss and operation time, as well as reducing pain intensity with 48 h postoperatively. Moreover, it produced shorter time to oral intake, time to ambulation, and length of hospitalization.[23,24] Considering these advantages, adrenalectomy is predominantly performed by PRA at our institution, except for patients with tumor sizes > 7 cm for pheochromocytoma and >10 cm for other adrenal tumors. Therefore, PRA is also preferred in robotic surgery, for similar reasons as laparoscopic surgery.

Despite no significant differences between the groups, the mean estimated blood loss was 14.8 mL less in the RA-SP group (2.5 ± 4.6 vs. 17.3 ± 18.5; $p = 0.255$). Moreover, the mean length of hospitalization was shorter in the RA-SP group (2.5 ± 0.5 [range 2–3] vs. 3.4 ± 1.1 [range 2–6]; $p = 0.220$). There may be a difference in the mean length of hospitalization in the RA-SA group because two Cushing's syndrome patients underwent steroid replacement up to 3 days post-surgery and one patient under warfarin had a history of cardiovascular disease and cerebral hemorrhage. These patients were hospitalized for 6 days post-surgery to control the international normalized ratio level. There were only two cases (18.2%) of laparoscopic conversion in the RA-SA group with additional single-port insertion due to the abundant perinephric fat tissue. There was no difference in the mean operation time ($p = 0.434$), however it would be meaningful that we were able to reduce the time moderately in the starting stage.

RA-SA had a moderately longer mean docking time of 2.6 min owing to the difficulty of putting four arms into a single port through the glove port in a small operation field. RA-SP comprised a slightly longer mean console time of 8.2 min, which could be the possible outcome of a learning curve that needs to be overcome; we intend to conduct a study on the learning curve in future. Moreover, the absence of an energy device in the da Vinci SP robotic system might have caused a delay in the operation owing to dissection difficulties. The tumor size was small and most patients were diagnosed with primary hyperaldosteronism (75%). Nonetheless, the mean operation time for RA-SP will likely be shorter as future experiences are accumulated.

The previous multi-arm robotic system had several advantages over laparoscopic surgery in performing the operation in a narrow space using a single incision because of a 3D working field with a magnified view, tremor-filtering multi-articulated instruments, and the possibility of meticulous manipulation.[9] Nevertheless, the collision of multiple arms resulted in discomfort, which required the assistant to put in an effort to alter the position of the arms during the operation. In contrast, the da Vinci SP robotic system operates with a flexible camera and three articulated working arms through a 2.5 cm cannula. Thus, collision between the arms is relatively small (Video 3). In addition, the efficient arrangement of arms almost eliminates blind spots in the visual or instrument reach. In the case of PRA using the multi-arm robotic system, all robot instruments invaded the skin at a shallow entry angle. Therefore, the external joint of the robot arm touched the patient's body, imposing movement limitations. However, the SP robotic system did not impose such restrictions as the device invaded a single port and the arms were spread out from the inside. Furthermore, the entry angle of the device was steep, relative to the skin, which in turn reduced the role of the surgical assistant outside the console. In addition, the 3 cm small single incision was an advantage of the cosmetic effect; RA-SA was also performed with a 3-cm incision. However, in several cases, the size of the incision was increased post-surgery because of the tension caused by arm movements during surgery. These incision size changes were small during RA-SP.

A limitation of RA-SP was that it progressed for an adrenal tumor size < 4 cm and BMI < 30 kg/m^2. However, in the RA-SA group, despite the initial progression in small tumors < 2 cm, it progressed in large tumors up to 7 cm. Therefore, improvement in the surgeon's experience will likely expand the optimal criteria of the tumor size. In future, further prospective or multicenter studies are warranted to evaluate the operative outcomes and to verify the technical feasibility of RA-SP.

CONCLUSIONS

This is the first report on the surgical outcomes of RA-SP. Compared with RA-SA, RA-SP did not differ significantly in surgical outcomes. In addition, RA-SP not only enhanced the cosmetic effect of patients but also facilitated easier and more convenient operations for surgeons. Therefore, the novel technique using the da Vinci SP robotic system is feasible and safe for adrenalectomy.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1245/s10434-021-11208-2.

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DISCLOSURE In A Lee, Jin Kyong Kim, Kwangsoon Kim, Sang-Wook Kang, Jandee Lee, Jong Ju Jeong, Kee-Hyun Nam, and Woong Youn Chung have no conflicts of interest or financial ties to disclose.

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