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Comparison of intraoperative and short-term postoperative outcomes between robot-assisted laparoscopic multi-port pyeloplasty using the da Vinci Si system and single-port pyeloplasty using the da Vinci SP system in children

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Purpose: We compared the intraoperative and postoperative outcomes of single-port robot-assisted laparoscopic pyeloplasty (S-RALP) using the da Vinci SP® system and conventional multi-port robot-assisted laparoscopic pyeloplasty (M-RALP) in pediatric patients.

Materials and Methods: Multi-port and single-port pyeloplasty have been performed in pediatric patients in our institution since October 2015 and February 2019, respectively. We conducted an entire cohort comparison. Considering the learning curve of M-RALP, we defined the last 15 cases of M-RALP as a subgroup of M-RALP and compared this subgroup with the entire cohort of S-RALP patients.

Results: Thirty-one patients who underwent multi-port pyeloplasty and 15 patients who underwent single-port pyeloplasty were enrolled in this study. Age, height, body weight, laterality, surgical indication, and ipsilateral differential renal function were statistically similar in the M-RALP and S-RALP groups. The median operative time (3.0 h vs. 2.4 h; p=0.01) and the median console time (2.2 h vs. 1.5 h; p<0.001) were longer in the M-RALP group than in the S-RALP group. There was no significant difference in operative time or console time between the M-RALP subgroup and the S-RALP group. There were no significant differences in the length of hospitalization, pain score, morphine-equivalent use of analgesics, or postoperative differential renal function in all comparisons.

Conclusions: This study confirmed that pyeloplasty using the da Vinci® SP system can be started by robotic surgeons who can overcome the learning curve. Robot-assisted laparoscopic single-port pyeloplasty is feasible in noninfant pediatric patients.

Keywords: Pediatrics; Robotic surgical procedures; Ureteral obstruction

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INTRODUCTION

In pediatric patients, ureteropelvic junction obstruction (UPJO) can cause flank pain, progressive hydronephrosis, and renal dysfunction and predispose children to urinary tract infections (UTIs). Laparoscopic pyeloplasty (LP) was first reported in the field of pediatric urology in 1995 by Peters et al. [1]. The advent of minimally invasive surgical techniques has led to decreased postoperative pain, improved cosmesis, and shortened hospital stays; therefore, LP has been widely accepted, with a success rate comparable to that of open pyeloplasty [2]. However, LP has a steep learning curve, and the instruments have limitations [3]. More recently developed robotic surgical platforms have several advantages over traditional laparoscopy because they provide optical magnification, stereoscopic vision, tremor filtration, operator-controlled camera movement, instrument indexing, and a high degree of freedom of instruments [4]. In 2004, Peters [5] reported on the use of the da Vinci® Surgical System (Intuitive Surgical, Sunnyvale, CA, USA) to perform pyeloplasty in pediatric patients.

Laparoendoscopic single-site surgery (LESS) has been applied in urology from the mid-2000s. Initially, it was expected that LESS would be advantageous with respect to cosmesis and recovery time; hence, it was used as a minimally invasive technique [6]. However, LESS is associated with difficulties in triangulation between instruments, has spatial limitations, and is associated with relative difficulties in instrument replacement. These drawbacks pose challenges as they make intracorporeal suturing and traction difficult and can cause the clashing of instruments.

To overcome the disadvantages associated with LESS, the da Vinci SP® surgical system was developed. It combines the advantages of the robotic surgical platform with those of LESS. The first study that investigated the use of this surgical system was published in 2019 [7-9].

Conventional multi-port robot-assisted laparoscopic pyeloplasty (M-RALP) is a surgical option that has been validated in several previous studies [3,10]. We present the steps of single-port robot-assisted laparoscopic pyeloplasty (S-RALP) using the da Vinci SP surgical system in pediatric patients with UPJO. We aimed to investigate the feasibility of S-RALP by comparing intraoperative and postoperative outcomes of S-RALP with the outcomes of M-RALP.

MATERIALS AND METHODS

This study was approved by the Institutional Review Board of Severance Hospital (approval number: 4-2020-0164). All patients signed an informed consent after the novel robotic system had been explained to them.

1. Surgical techniques and postoperative management

M-RALP and S-RALP were performed by using multiple ports and a single port, respectively. In the case of M-RALP (the da Vinci Si® surgical system), four port placements were made: one 8.5-mm camera port, two 5-mm robotic arm ports, and one 5-mm assist port. When the right side was operated on, the third arm was not used. When liver traction was required, assistant instruments were used.

For S-RALP, a 25- to 30-mm umbilical incision was made to reach the peritoneal cavity, and the GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA) was inserted. A 25-mm multi-channel port containing an articulating robotic camera, two double-jointed robotic instruments, and a 12-mm port for an assistant's laparoscopic instrument were placed through the GelSeal cap. Among patients in the S-RALP group, two patients underwent operation on the right side, and in these cases, a third arm was required when performing S-RALP. During S-RALP, additional port insertion is not required for the third arm, because it can be inserted through the 25-mm multi-channel port. We used instruments according to the situation through a multi-channel port; the instruments used included the Maryland dissector, curved scissor, permanent cautery hook, and wristed needle driver.

Placement of the 25-mm multi-channel port and movement of the robotic instruments are limited with respect to distance in pediatric patients. The distance between the site of the single port and the target needs to be at least 15 cm, with a maximum of 27 cm [11]. The minimum distance is often difficult to establish, even with the formation of a pneumoperitoneum. Instead of placing the multi-channel tip into the abdominal cavity, we placed it into the GelPOINT to form a "floating dock," which equated to a distance gain of approximately 3 to 3.5 cm. We used the floating dock in all patients who underwent S-RALP (Fig. 1).

The surgical steps after port insertion were almost identical in both groups. In Severance Hospital, we use a transperitoneal colon reflecting approach to confirm the overall morphology of the ureter and to more accurately identify crossing vessels. The double-J ureteral stent was inserted with the antegrade method. Anastomosis was performed in an interrupted manner using Vicryl 6-0 or 5-0 sutures, depending on the caliber of the patient's ureter.

For patients in both the M-RALP and the S-RALP groups, ureteral stents were removed 1 month postoperative-

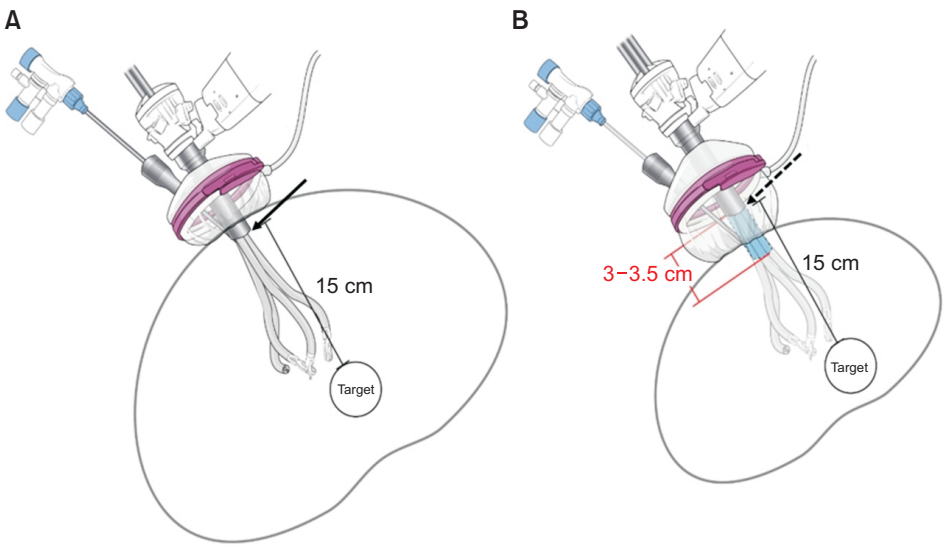

Fig. 1. "Floating dock" to secure the minimum distance to the target. (A) According to Cruz et al. [11], the distance between the tip of the multi-channel port (black arrow) and the target must be at least 15 cm. (B) For pediatric patients or patients with a small abdominal cavity, a "floating dock" can be formed to ensure a distance of 15 cm or more. The dotted arrow indicates the multi-channel port tip in a "floating dock."

ly. Stent removal was performed in a 1-day surgery, using an 8 Fr pediatric cystoscope. Retrograde pyelography was performed under general anesthesia, and stent removal was performed if there was no leak. Patients underwent ultrasonography 1–3 months, 6 months, and then annually after ureteral stent removal. Mercaptoacetyltriglycine-3 (MAG-3) renal scan was routinely performed around 6 months after surgery.

2. Patients and design

This was a retrospective study conducted among pediatric patients enrolled in a Severance Hospital in Korea. The indications for UPJO repair surgery included refractory flank pain, worsening hydronephrosis, recurrent UTI, and impaired differential renal function (DFR; <40%) or a decrease in split renal function of >10% in subsequent studies.

M-RALP has been conducted in 31 pediatric patients since October 2015, and S-RALP was performed in 15 consecutive patients from February 2019 to January 2020 using the da Vinci SP surgical system. The last patient underwent M-RALP after four patients underwent S-RALP because there was a problem with the supply of the robotic arm of the da Vinci SP surgical system. A single surgeon (Y.S.L.) performed the surgeries in both groups.

3. Surgical modality selection

Open pyeloplasty is frequently performed in infants aged <3 months, and LP is performed in infants aged >3 months. From around 12 months of age, LP and RALP are offered as surgical options to the guardians of children who require pyeloplasty.

In the National Korean Health Insurance system, the surgical fees for open pyeloplasty and LP are covered by the national health insurance, but the surgical fee for RALP is not. Other hospital charges (including those for the operating room, anesthesia, post-anesthesia care unit, additional surgical supplies, laboratory, pharmacy, and inpatient room) are equally covered by the national health insurance. The surgical fee for RALP (approximately US$5,800) is 6 to 12 times the surgical fee for LP, depending on the age of the child. Therefore, the economic status of a patient's guardians and whether they have private health insurance coverage may affect the selection of the treatment option.

4. Data collection

Patient characteristics that were evaluated included age, height, body weight, body surface area, surgical indication, and preoperative hydronephrosis Society of Fetal Urology (SFU) grade and DRF.

Intraoperative data included information on operative time, console time, average number of replaced robotic instruments, average exchange time per robotic instrument, intraoperative complications, estimated blood loss, and conversion to another surgical modality. Operative time was measured from the creation of the skin incision to wound closure after robotic surgery. After docking the robotic instruments, the console time was calculated from the time of commencement of the surgery to the end of the robotic operation. The number of exchanges of robotic instruments during surgery and the time spent on these exchanges were determined by reviewing the video clip.

Postoperative outcomes included length of hospitalization, additional morphine-equivalent use of analgesics during hospitalization (during a patient's hospital stay, we administered acetaminophen 15 mg per kg body weight three times a day as a routine analgesic), pain-rating scale score

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on postoperative day 1, follow-up period, number of follow-up visits, readmission, and postoperative DRF. During hospitalization and during the follow-up period, the Clavien–Dindo classification was used to grade the severity of postoperative complications [12]. Postoperative pain was measured by using the Wong–Baker FACES pain-rating scale [13].

5. Statistical analysis

In the entire cohort analysis, the characteristics and intraoperative and postoperative outcomes of the M-RALP and S-RALP groups were compared. Considering the learning curve for the use of M-RALP [14], we also conducted a subgroup analysis. We compared the outcomes of the last 15 cases in the M-RALP group with those in the S-RALP group. Two groups were compared by using nonparametric analysis (Mann–Whitney U-test) and Fisher's exact tests (SPSS, version 25.0; IBM Corp., Armonk, NY, USA). A p-value less than 0.05 was considered statistically significant.

RESULTS

1. Entire cohort comparison

Overall, 46 patients were included in this study, of whom 31 (67.4%) and 15 (32.6%) were classified into the M-RALP and S-RALP groups, respectively. All procedures were successfully completed using a robotic surgical system without additional port placement or conversion to other surgical modalities.

Table 1. Patients' demographic characteristics and preoperative data

Variable	M-RALP	S-RALP	p-value
Age at OP (y)	7.1 (4.9–9.1)	7.6 (6.3–11.0)	0.35
Height at OP (cm)	120.3 (111.6–135.0)	124.0 (121.0–145.8)	0.17
Body weight (kg)	23.3 (18.5–27.9)	26.1 (21.1–47.1)	0.22
BSA (m^2)	0.88 (0.76–1.04)	0.95 (0.83–1.41)	0.36
Laterality (left:right)	27:4	10:5	0.13
Surgical indication			0.08
Dietl's crisis	21 (67.7)	15 (100.0)	
Prenatal hydronephrosis	3 (9.7)		
Recurrent UTI	2 (6.5)		
Decreased DRF	5 (16.1)		
Ipsilateral DRF	48.0 (41.0–51.0)	48.3 (43.0–51.4)	0.48
Pre-op SFU grade III/IV	16/15	10/5	0.37

Values are presented as median (interquartile range), ratio, number (%), or number only.
M-RALP, multi-port robot-assisted laparoscopic pyeloplasty; S-RALP, single-port robot-assisted laparoscopic pyeloplasty; OP, operation; BSA, body surface area; UTI, urinary tract infection; DRF, differential renal function; SFU, Society of Fetal Urology.

Table 2. Comparison of intraoperative and postoperative outcomes between entire cohorts

Variable	M-RALP	S-RALP	p-value
Operative time, skin to skin (h)	3.0 (2.5–3.6)	2.4 (2.2–2.7)	0.01
Console time (h)	2.2 (1.7–2.7)	1.5 (1.3–1.7)	<0.001
Average number of replaced RI (time)	6 (4–7)	3 (3–4)	<0.001
Average exchange time per RI (s)	22 (20–25)	75 (61–86)	<0.001
Total time taken to exchange RI (s)	129 (102–164)	191 (172–385)	<0.001
EBL (mL)	50–200	<50	
Hospital stay (day)	5 (5–6)	5 (4–6)	0.55
Pain score on POD 1	2 (1–4)	2 (1–4)	0.73
Morphine-equivalent use of analgesics	0.1 (0.1–0.1)	0.1 (0.1–0.3)	0.18
Postoperative DRF	48.0 (42.1–52.0)	46.5 (45.0–48.8)	0.38
DRF changes	1.0 (-1.0 to 2.0)	-1.8 (-2.5 to 2.0)	0.07
Follow-up (mo)	27.4 (11.0–34.9)	3.2 (2.1–6.9)	<0.001
Number of follow-up visits	4 (3–4)	2 (1–2)	<0.001

Values are presented as median (interquartile range) or range.
M-RALP, multi-port robot-assisted laparoscopic pyeloplasty; S-RALP, single-port robot-assisted laparoscopic pyeloplasty; RI, robotic instruments; EBL, estimated blood loss; POD, postoperative day; DRF, differential renal function.

Table 3. Demographic characteristics and perioperative data in the last 15 cases of M-RALP and the entire S-RALP cohort

Variable	M-RALP15	S-RALP	p-value
Age at OP (mo)	7.7 (4.8–11.6)	7.6 (6.3–11.0)	0.90
Height at OP (cm)	120.3 (111.6–155.0)	124.0 (121.0–145.8)	0.57
Body weight (kg)	25.2 (20.0–57.8)	26.1 (21.1–47.1)	0.84
BSA (m^2)	0.95 (0.79–1.66)	0.95 (0.83–1.41)	>0.99
Laterality (left:right)	13:2	10:5	0.39
Surgical indication			0.177
Dietl's crisis	10 (66.7)	15 (100.0)	
Decreased DRF	4 (26.7)		
Prenatal hydronephrosis	1 (6.7)		
Ipsilateral DRF	46.0 (41.0–50.0)	48.3 (43.0–51.4)	0.37
Pre-op SFU grade III/IV	8/7	10/5	0.71

Values are presented as median (interquartile range), ratio, number (%), or number only.
M-RALP15, last 15 cases of multi-port robot-assisted laparoscopic pyeloplasty; S-RALP, single-port robot-assisted laparoscopic pyeloplasty; OP, operation; BSA, body surface area; DRF, differential renal function; SFU, Society of Fetal Urology.

The patient characteristics and preoperative data did not differ significantly between the two groups (Table 1). The intraoperative and postoperative outcomes are shown in Table 2. The median operative times were 3.0 hours (interquartile range [IQR], 2.5–3.6 h) and 2.4 hours (IQR, 2.2–2.7 h) in the M-RALP and S-RALP groups, respectively (p=0.01). The median console time significantly differed between the M-RALP and S-RALP groups (median, 2.2 h [IQR, 1.7–2.7 h] vs. median, 1.5 h [IQR, 1.4–1.7 h]; p<0.001). During surgery, the number of robotic instruments exchanged was higher in the M-RALP group than in the S-RALP group (p<0.001), but the total time taken to exchange the instruments (p<0.001) and the average time taken for the exchange of one instrument were higher in the S-RALP group (p<0.001).

There was no significant difference in the pain score at postoperative day 1 between the two groups (p=0.73); furthermore, there was no significant difference in the number of analgesics used during the hospital stay (p=0.55).

There was a difference between the two groups in the follow-up period (p<0.001) and the number of follow-up visits (p<0.001) after surgery. After surgery, the results of the MAG-3 renal scan were confirmed in all patients undergoing M-RALP. In the S-RALP group, MAG-3 results were available for 10 patients. There was no significant difference in DRF changes between the two groups before or after surgery (p=0.07).

One patient in the M-RALP group developed flank pain after stent removal on postoperative day 33; therefore, the ureteral stent was replaced. Three months later, the stent was removed, and there were no further complications, including pain. In the remaining patients, the severity of perioperative complications did not exceed Clavien–Dindo classification grade I.

2. Subgroup comparison

There were no significant differences in patient characteristics when the last 15 M-RALP cases were compared with the S-RALP cases (Table 3). There were also no significant differences in operative time (p=0.78) or console time (p=0.81) between the groups (Fig. 2). The number of robotic instruments exchanged was higher in the M-RALP subgroup than in the S-RALP group (p<0.001), but the total time taken to exchange instruments and the average time taken to exchange one instrument were higher in the S-RALP group than in the M-RALP subgroup (p<0.001 and p<0.001, respectively) (Table 4).

DISCUSSION

In 2011, Sorensen et al. [14] published a study on the learning curve of pyeloplasty performed in pediatric patients using the da Vinci standard surgical system and reported that the curve was overcome after 15 to 20 cases. Within the M-RALP group in the present study, the operative time and console time in the last 15 cases (M-RALP subgroup) were significantly shorter than in the previous 16 cases (p<0.001 and p<0.003, respectively). Although the M-RALP group included cases from the time before the learning curve was overcome, S-RALP was generally implemented after M-RALP. However, the difference in operative time between the two groups was significant. The console times of the two groups differed, and the console time in the S-RALP group was significantly shorter than that in the M-RALP group. Considering that there were no significant differences in operative time or console time between the M-RALP subgroup and the S-RALP group, the transition to S-RALP was not technically difficult for surgeons with sufficient M-RALP

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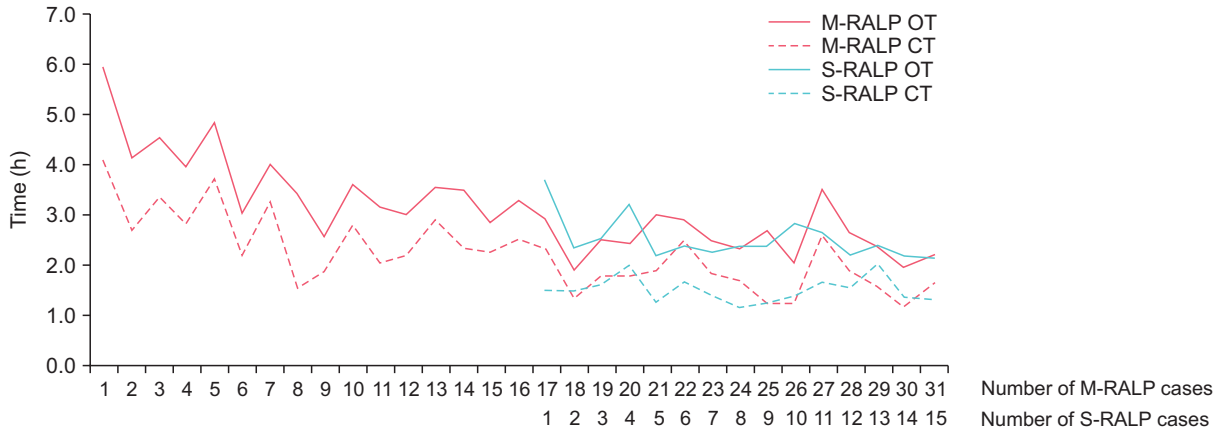

Fig. 2. Operative time and console time according to surgeon experience. Values of the operative time (OT, solid line) and console time (CT, dotted line) from 31 cases of multi-port robot-assisted laparoscopic pyeloplasty (M-RALP) and 15 cases of single-port robot-assisted laparoscopic pyeloplasty (S-RALP) are plotted. We carried out S-RALP directly after M-RALP in all cases except for the last. For subgroup comparison, the OT and CT for the last 15 cases of M-RALP and S-RALP are plotted together.

Table 4. Intraoperative and postoperative outcomes of the last 15 cases of M-RALP and the entire S-RALP cohort

Variable	M-RALP15	S-RALP	p-value
Operative time, skin to skin (h)	2.5 (2.2–2.9)	2.4 (2.2–2.7)	0.78
Console time (h)	1.8 (1.4–1.9)	1.5 (1.3–1.7)	0.81
Average number of replaced RI (time)	5 (4–6)	3 (3–4)	<0.001
Average exchange time per RI (s)	23 (20–25)	75 (61–86)	<0.001
Total time taken to exchange RI (s)	107 (91–129)	191 (172–385)	<0.001
EBL (mL)	50–200	<50	
Length of hospitalization (day)	5 (4–5)	5 (4–6)	0.34
Pain score on POD 1	2 (0–3)	2 (1–4)	0.74
Morphine-equivalent use of analgesics	0.1 (0.1–0.1)	0.1 (0.1–0.3)	0.25
Postoperative DRF[a]	48 (43.0–51.0)	46.5 (45.0–48.8)	0.53
DRF changes	0.7 (-1.0 to 2.0)	-1.8 (-2.5 to 2.0)	0.18
Follow-up (mo)	11.0 (8.4–15.4)	3.2 (2.1–6.9)	<0.001
Number of follow-up visits	4 (2–4)	2 (1–2)	0.01

Values are presented as median (interquartile range) or range.
M-RALP15, last 15 cases of multi-port robot-assisted laparoscopic pyeloplasty; S-RALP, single-port robot-assisted laparoscopic pyeloplasty; RI, robotic instruments; EBL, estimated blood loss; POD, postoperative day; DRF, differential renal function.
[a]:MAG3 results were available for 10 patients in the S-RALP group.

experience (Fig. 2). Console manipulation was shown to be similar between the M-RALP and S-RALP groups.

In our S-RALP group, the youngest patient was 3.8 years old, 105 cm tall, and weighed 17.5 kg. In pediatric patients, we used a floating dock to overcome the distance limit in implementing S-RALP. The floating dock afforded us an additional distance of approximately 3 to 3.5 cm. However, creating and using this floating dock is expected to affect the S-RALP learning curve.

There were disadvantages in using the floating dock. During surgery, the number of instrument replacements for M-RALP was higher than that for S-RALP. Moreover, in the subgroup analysis, the number of replacements was higher in the M-RALP group. However, it was confirmed that the number of device replacements was approximately one more; hence, this difference was not significant. However, the time taken for replacement was approximately 120 seconds longer in the S-RALP group, and this appears to be due to the use of the floating dock. In M-RALP, when the robotic instrument is replaced, the instrument is replaced by a port; therefore, there is no difficulty in performing a quick replacement. When replacing the robotic instrument in S-RALP using the floating dock, the instruments may crash inside the dock. Therefore, backward motion of the camera is required, and thus, a camera is required to monitor the progress of the robotic instruments approaching the opera-

tion field. This shows that rapid instrument changes may be difficult in highly complex cases. Therefore, M-RALP may be effective in surgeries in which frequent exchange of robotic instruments is expected owing to high complexity or the presence of severe adhesions.

Similarly, we expected that S-RALP would reduce the recovery time and the morphine-equivalent use of analgesics, compared to those in LESS. However, the length of hospital stay was no longer in the M-RALP group than in the S-RALP group, and the difference in morphine-equivalent use of analgesics (except routine analgesics) in patients during hospitalization was not significant. The cost borne by the patient during a hospital stay in South Korea is lower than in the United States because of the National Health Insurance system. This frequently leads to a delay in the patient's discharge from the hospital (an average of $10–$100 per day, excluding the surgery fee). This situation in Korea may explain why the duration of hospital stay in our study was longer than what was reported by studies in the USA [15,16].

Our study has several limitations. First, it was a retrospective study, with a small number of enrolled cases. Second, only one surgeon conducted the surgical techniques. Finally, because of the recent introduction of the da Vinci SP system, we were able to present only relatively short-term S-RALP outcomes. It will be necessary in the future to study the learning curve for S-RALP performance with no prior M-RALP experience. In this study, M-RALP and S-RALP were not conducted at the same time, and the superiority of S-RALP over M-RALP could not be proven. The feasibility of S-RALP in noninfant pediatric patients was confirmed by a surgeon who overcame the learning curve of M-RALP. However, future studies should evaluate the long-term outcomes of S-RALP.

CONCLUSIONS

Our study findings suggest that pyeloplasty using the da Vinci SP system can be initiated by robotic surgeons who can overcome the learning curve. Long-term postoperative outcomes must be assessed to further verify the feasibility of robot-assisted laparoscopic single-port pyeloplasty in noninfant pediatric patients.

CONFLICTS OF INTEREST

The authors have nothing to disclose.

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AUTHORS' CONTRIBUTIONS

Research conception and design: Yong Seung Lee. Data acquisition: Sung Hoon Kim. Statistical analysis: Sung Ku Kang. Data analysis and interpretation: Sung Ku Kang. Drafting of the manuscript: Sung Ku Kang. Critical revision of the manuscript: Yong Seung Lee. Administrative, technical, or material support: Won Sik Jang and Sang Woon Kim. Supervision: Sang Won Han. Approval of the final manuscript: Yong Seung Lee.

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