의학석사 학위논문

A retrospective multicentre study on the evaluation of perioperative outcomes of single-port robotic cholecystectomy comparing the Xi and SP versions of the da Vinci robotic surgical system

다빈치 로봇 수술 시스템의 Xi 및 SP 버전을 비교한 단일 포트 로봇 담낭 절제술의 수술 전후 결과 평가에 대한 다기관 후향적 연구

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A retrospective multicentre study on the evaluation of perioperative outcomes of single-port robotic cholecystectomy comparing the Xi and SP versions of the da Vinci robotic surgical system

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이 논문을 의학석사 학위논문으로 제출함

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Abstract

Background: Single-incision robotic cholecystectomy (SIRC) is widely performed with both the da Vinci Xi system (Xi) and the da Vinci SP system (SP). But there are limited numbers of studies comparing these platforms.
Methods: Patients who underwent SIRC between 2019 and 2020 were enrolled. Patient demographics, intraoperative factors, postoperative complications, postoperative pain were compared using a one-to-one propensity score matching (PSM).
Results: Overall, 258 patients underwent SIRC with Xi and 72 with SP. After PSM, the operation time at console (Xi 26.3 vs. SP 19.6 min, $p = 0.015$) and numeric rating scale for postoperative pain (Xi 6.1 vs. SP 4.9, $p < 0.001$) was significantly lower in SP group, but no difference in total operation time (Xi 48.9 vs. SP 45.7 min, $p = 0.323$) and postoperative complications (Xi 0.0% vs. SP 0.0%, $p > 0.999$). The SP group showed more estimated blood loss (Xi 10.6 vs. SP 18.1 ml, $p = 0.049$).
Conclusions: Despite the statistical difference, clinical benefit was not significant. Both platforms can be safe and feasible to perform SIRC, but further investigation including the surgeon's workload and ergonomics is needed as a prospective study.

Keywords : cholecystectomy, Da Vinci SP, Da Vinci Xi, robotic surgery
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Chapter 1. Introduction

With the increasing demand for minimally invasive surgery, laparoscopic cholecystectomy (LC) has become the gold standard in patients with benign gallbladder disease indicated for surgery.[1-3] Single-incision laparoscopic cholecystectomy (SILC), which is performed using a single-port technique through only one incision in the periumbilical area, has been developed for better cosmetic outcomes and minimization of surgical wound.[2,4-7]

However, the disadvantages of SILCs have been revealed. Surgeon fatigue caused by collision of two arms was not ignorable; therefore, many surgeons felt discomfort in controlling instruments.[6]

To overcome the limitations of SILC, a robotic platform known as the da Vinci robotic single-site surgery (RSSS) has been introduced for single-incision technique. The number of cases of single-incision robotic cholecystectomy (SIRC) performed by RSSS has recently increased. The da Vinci Xi system (Intuitive Surgical, Sunnyvale, CA, USA) (Xi) is an RSSS platform with multiple arms installed. The multi-arms bend flexibly as they pass through the umbilical single port, enabling easier movement of instruments. In combination with these improved ergonomics, three-dimensional visualization is provided, resulting in significant reduction of mental and physical stress in surgeons and shorter hospital stay in patients with comparable postoperative outcomes.[8-10]

With recent technology, the da Vinci SP (SP) emerged, which is even more specialized for single-incision surgery. SP is characterized by a single arm that has three different instruments and a camera inside it and endowrist motion with multiple joints. Thus, SP has the advantages of a shorter docking time, no collisions and trapping between each instrument, and minimal pressure on the incision site.[11-13]

However, there are only a few studies and a limited number of study samples comparing the new single-port technology with previously widely used RSSS in cholecystectomy. Therefore, we aimed to compare RSSS with Xi and SP performing SIRC in terms of perioperative outcomes

Chapter 2. Materials and methods

1. Patients

Patients who underwent SIRC with Xi and SP at Seoul National University Hospital (SNUH) and Ewha Womans University Seoul Hospital (EWUSH) between February 2019 and November 2020 were enrolled in this study. The indications for SIRC were benign gallbladder diseases such as gallbladder stones, polyposis, adenomyomatosis, and acute cholecystitis. All patients were at least 18 years of age. Patients with the following were excluded: bleeding tendency, pregnancy, open or laparoscopic conversion after exploration, additional resection of other organ(s), and American Society of Anesthesiologists (ASA) physical status classification grade 3 or more (Figure 1).[14]

Clinicopathologic data were collected retrospectively and recorded in an electronic medical database. The following clinical variables were investigated: age, sex, body mass index (BMI), smoking history, hypertension, diabetes mellitus, chronic obstructive pulmonary disease, ASA classification, previous history of abdominal surgery, preoperative laboratory results (albumin and total bilirubin levels), presence of symptoms, preoperative acute cholecystitis, preoperative common bile duct stone removal, diagnosis, total operation time, console operation time, estimated blood loss (EBL), red blood cell transfusion, and insertion of drainage.

Postoperative complications were also assessed. Complications included surgical (bile duct injury, bleeding, bowel injury, wound infection) and medical complications (pneumonia, pulmonary thromboembolism, postoperative use of ventilator for >48 h, unexpected intubation, myocardial infarction, unstable angina, urinary infection, acute renal failure, urinary dysfunction, delirium, stroke, and systemic inflammatory response syndrome, including sepsis). Length of hospital stay, postoperative transfer to other medical centres, and unexpected readmission were investigated.

In addition, postoperative pain was evaluated using a numeric rating scale (NRS).[15] NRS was checked on the day of operation and postoperative day (POD) 1. Analgesics were given when patients required them, and the number of analgesics administered was counted. Analgesics were delivered in two ways: intravenous or intramuscular injection and oral medication.

The costs were evaluated in each platform of robotic cholecystectomy. The costs of robotic instruments and accessories used in single case were calculated. This study was approved by the Institutional Review Board (IRB) of Seoul National University (IRB no. 2011-155-1176).

2. Surgical procedure

2.1 SIRC with Xi

Under general anaesthesia, the patient was placed in supine position. A 2-cm umbilical skin incision was made for the single port, and it was deepened and extended to 2 cm at the level of the fascia. The peritoneal cavity was approached using the open technique. Through the incision, a glove port® (NELIS Medical, Bucheon, South Korea) was inserted. A pneumoperitoneum was made with 12-15 mmHg intra-abdominal pressure. The robotic platform was placed over the right shoulder and docked to a Glove Port® (Figure 2). The surgeon moved to the console and started the operation.

The patient was positioned in reverse Trendelenburg and slightly tilted to the left. The grasping forceps were introduced inside the patient's abdominal cavity grasping the gallbladder fundus using forceps. Calot's triangle was visualized for safe dissection by retracting the gallbladder in the superolateral direction. The cystic duct and artery were carefully dissected and ligated using clips. The gallbladder was dissected from the liver bed and removed through the umbilical port. After meticulous haemostasis, the fascia and skin were closed with absorbable interrupted sutures.

2.2 SIRC with SP

The patient was placed in supine position under general anaesthesia in the same manner as SIRC was performed with Xi. A 2.5-cm umbilical incision was made for a single port, and the robot platform was docked with a pneumoperitoneum (Figure 3). The camera was inserted at the lower middle hole, a fenestrated bipolar forceps for the left hole (arm 1) controlled by the left hand, a cadiere forceps for the upper-middle hole (arm 2) controlled interchangeably with the left and right hands, and a hook or Maryland bipolar forceps for the right hole (arm 3) controlled by the right hand.

Since there were no assistant ports, arm 2 was used for superolateral traction of the gallbladder. The cystic duct and artery were dissected and ligated in the same manner as SIRC with Xi. The gallbladder was dissected from the bed and removed through the umbilical port. The fascia and skin were closed using absorbable interrupted sutures

3. Statistics

All statistical analyses were performed using SPSS (version 25.0;

SPSS Inc.). PSM was adapted to minimize selection bias and differences in the number of cases between the Xi group and the SP group. Propensity scores were calculated for all patients using a logistic regression model based on the preoperative factors including age, sex, BMI, history of major abdominal surgery, and presence of preoperative acute cholecystitis. A 1:1 matched analysis using the nearest-neighbour matching with a calliper distance of 0.1 without replacement was performed based on the calculated propensity score of all patients. Nominal data were compared using $\chi 2$ tests, and continuous data were examined using Student's t-test. Continuous variables were expressed as mean ± standard deviation (SD). Statistical significance was set at $p < 0.05$.

Chapter 3. Results

A total of 258 patients underwent SIRC with Xi and 72 patients with SP. A total of 115 patients (34.8%) were male, with a mean age of 47.1 years. The mean BMI was 24.1 kg/m^2 . Patients in the SP group were significantly younger than those in the Xi group (48.4 vs. 42.2 years, $p < 0.001$). However, there was no difference between the two groups regarding sex (male, 37.2% vs. 26.4%, $p = 0.118$) and BMI (24.0 vs. 24.7 kg/m^2, $p = 0.238$) (Table 1). Eight patients (3.1%) in the Xi group and one patient (1.4%) in the SP group had common bile duct stones preoperatively ($p = 0.704$).

In the SP group, 53 patients (73.6%) had symptoms preoperatively with 23 cases of preoperative acute cholecystitis (31.9%), compared to 96 patients with preoperative symptoms (37.2%) in the Xi group, with only four cases of preoperative acute cholecystitis (1.6%) ($p < 0.001$). Antibiotics were administered to all patients preoperatively. The final diagnosis showed a significant difference in 33 patients (12.8%) in the Xi group and 28 patients (38.9%) in the SP group ($p < 0.001$). Other diagnoses included gallbladder stones (50.4% vs. 52.8%) as the most common indication for cholecystectomy, polyps (27.9% vs. 5.6%), and adenomyomatosis (8.9% vs. 2.8%).

The intraoperative factors and postoperative outcomes, including pain evaluation, are summarized in Table 2. There was a significant difference between the Xi and SP groups in operation time at console (23.1 vs. 20.3 min, $p = 0.018$). However, no difference was seen in total operation time (43.4 vs. 45.9 min, $p = 0.155$). The SP group showed more EBL statistically (14.3 vs. 19.2 ml, $p = 0.031$), but there is no clinical meaningful blood loss in both groups.

In pain evaluation, patients in the SP group experienced less pain on both the day of operation (NRS 4.9 vs. 5.7, $p < 0.001$) and POD 1 (NRS 1.3 vs. 4.3, $p < 0.001$). Moreover, the number of postoperative analgesic injection was lesser in the SP group (3.2 vs. 4.0, $p < 0.001$). Other postoperative outcomes, including complications (0.8% vs. 0.0%, $p > 0.999$), showed no difference. There was one patient with ileus and one patient with postoperative oozing at the gallbladder bed in the Xi group without the need for further treatment, and there were no other complications such as bile duct injury, complicated fluid collection, or wound complications.

To reduce these discrepancies, a one-to-one propensity score-matched analysis was performed using five clinical variables; age, sex, BMI, history of previous abdominal surgery, and presence of preoperative acute cholecystitis. After PSM, most of the demographic characteristics were comparable.

In perioperative outcomes, consistent tendency was observed after PSM; comparable time of operation (48.9 vs. 45.7 min, $p = 0.323$), and shorter operation time at console in the SP group (26.3 vs. 19.5 min, $p = 0.015$), more blood loss in the SP group (10.6 vs. 18.1 ml, $p = 0.049$), and less pain at day of operation (NRS 6.1 vs. 4.9, $p < 0.001$) and POD 1 (NRS 4.3 vs. 1.2, $p < 0.001$) in the SP group. There was no patient with postoperative complications in both groups after PSM.

The total costs for robotic instruments and accessories in single case were higher in SP group than Xi group (₩ 1,252,433 vs. ₩ 2,334,215) (Table 3). Although the costs of accessories used when inserting ports were slightly higher in Xi group (₩ 9,873 vs. ₩ 4,455), the costs of instruments were higher in SP group(₩ 940,610 vs. ₩ 1,460,195).

Chapter 4. Discussion

Technology in surgery has continued to evolve and is now more advanced than ever.[2,16-20] The advent of robotic platform combined with single-site skill for laparoscopic surgery is getting great attention from surgeons because of its improvement in cosmesis and reduction of surgeon's stress load.[4,8] In a previous study in our centre, early experience of SIRC with Xi was demonstrated with a rapid learning curve and no major complications such as common bile duct injury or gallbladder perforation.[10] Moreover, in another study, three-port laparoscopic cholecystectomy (3PLC), SILC, and SIRC were compared, showing good cosmetic outcome and low workload with similar postoperative outcomes in SIRC.[4]

Recently, SP, the most recent model of robotic surgical platforms, has been applied for minimally invasive surgery in various surgical fields. Its main feature is having a single arm that needs to be docked only once, making the docking process much simpler than the previous multi-arm platform. In addition, its multi-joint endowrist instruments provide distal triangulation, enabling access to narrow spaces. Moreover, the third arm, which is controlled directly by the surgeon, also has a multi-joint endowrist allowing proper traction of the anatomical structure in all directions when needed.

Currently, there are a small number of studies comparing previous multi-arm platforms and SP systems in the overall surgical field. Moschovas et al. compared perioperative outcomes in radical prostatectomy with multiple-incision Xi and single-incision SP.[21] In this study, despite the faster trocar placement and docking, the total operative time and console time were longer, which may be due to the limitations of the SP in tissue dissection and traction capacity. Using a single-incision Xi, Lee et al. reported performing sacrocolpopexy with a shorter docking time and cervix suturing time in SP compared to that in Xi, but a slightly longer incision (2.7 vs. 2.5 cm).[22]

In terms of cholecystectomy with single-incision Xi and SP, Cruz et al. reported significantly shorter docking time, actual dissection time, console time, and total operation time with significantly less pain and comparable perioperative complication.[11] However, the absence of an accessory port was worrisome because delivery of needed materials was difficult and immediate intervention by an assistant surgeon such as suctioning of the bile leak or bleeding was impossible unless an additional port was inserted. Since this is the only reported literature comparing Xi and SP in SIRC, little is known about their perioperative outcomes.

In the present study, although there was no significant difference in the total time of operation between the two groups after PSM, operation time at console was remained shorter in the SP group (26.3 vs. 19.6 min, $p = 0.015$). This might be due to the multi-joint endowrist in SP, enabling a better approach to the surgical area, resulting in easier identification and dissection of anatomical structures. Although lower traction and tissue-gripping capacity are seen in SP, there are few procedures requiring retraction or grasping of a specific anatomy in SIRC, except for removing the gallbladder from liver. Furthermore, the difference in changing instruments at each arm might also have influenced the console time. In the da Vinci Xi, the positions where instruments are exchanged and mounted are spread widely from the left to right side of the patient's body. On contrary, since the devices are installed in only one position in the da Vinci SP, it is less time-consuming. However, the total operation time was comparable, implying that the clinical benefit of SP was not significant.

The advantages of the postoperative pain scores were also noted both before and after PSM. On the day of the operation, there was significantly less pain in the SP group, but the difference in values was small to consider clinical impact (NRS 6.1 vs. 4.9, $p < 0.001$). In contrast, a significant difference was found on POD 1 (NRS 4.3 vs. 1.2, $p < 0.001$). In the Xi system, the robotic arms were inserted through the port at the umbilical wound site. When surgeons manipulated the robotic arms extensively, the umbilical wound site could be pressed by the robotic arms, causing more postoperative pain.[23] In contrast, the common robotic port was inserted in the umbilical wound site, and the robotic arms were in the common port in SP. Therefore, the wound had constant pressure, regardless of the movement of the robotic arms. Although the incision size is slightly larger in SP (2.5 cm), a shorter operation time at the console might have a greater effect on postoperative pain, reducing exposure to these manipulations and pressure around the umbilical port. A relatively shorter time at the console may also have contributed to the reduction of pain generated by the capnoperitoneum.

The amounts of blood loss in both groups were less than 20 ml, considered minimal. Therefore, it is difficult to say that there is a difference, and the values were too small to have a clinical impact.

To our knowledge, this is the first study to compare clinical outcomes of SIRC comparing the two latest versions of the da Vinci platform. As cholecystectomy is usually a fairly simple and low-risk procedure, the instruments are not quite different between the two platforms. If the two platforms use the same device, there are no functional weaknesses such as haemostasis. Moreover, the learning curve for cholecystectomy did not seem to be different in each platform. However, when it comes to complex procedures, the authors agreed that there seems to be some weakness in SP. First, unlike Xi, SP requires additional incision and trocar for the participation of an assistant, which disrupts the major advantage of

SP. It is difficult to cope with situations such as intraoperative bleeding events without an assistant. Secondly, there is less diversity in surgical instruments such as energy device in SP currently, which can be required to deal with various situations in difficult procedures. Thirdly, the power for traction is relatively weak in SP, resulting in difficulty of clearing surgical view. For these reasons, expansion of indication is considered yet to be difficult in SP at this moment. On the other hand, SP has its advantage by having no collision of arms that sometimes even interferes with the surgery to proceed in Xi.

This study has several limitations. First, this study was performed using a small sample size, especially in the SP group. Secondly, because of the retrospective nature of the study and the clinical practice observed in separate centres, the protocol for postoperative pain management, detailed surgical procedures and selective criteria for surgery is not consistent between the two centres. Thirdly, there may be limitations on the application for other countries with different demographic configurations, such as BMI. In western countries, the average BMI is relatively high, and many studies report the relationship between high BMI and increased rate of port site hernia.[24] Furthermore, patients with high BMI might require a larger incision for safe insertion of port, resulting in a different pattern of pain compared to this study.

Lastly, cosmetic outcomes and surgeon's workload are important factors that should be considered in new platforms of surgery, but they are not included in the study. For these reasons, a well-designed prospective randomized study should be performed with a proper protocol and further information included. Nevertheless, this study is important because there are few studies comparing conventional RSSS and the latest SP.

Chapter 5. Conclusion

Postoperative pain and operation time at console were statistically less in the SP group. However, the clinical benefit does not appear to be significant, implying that both Xi and SP can be a safe and feasible platform to perform SIRC. However, due to the limitations of the retrospective design of this study, a well-designed prospective study is needed.

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초 록

배경 : 단일공 로봇 담낭절제술은 다빈치 Xi 시스템(Xi)과 다빈치 SP 시스템(SP) 모두를 이용하여 널리 시행된다. 그러나 이러한 플랫폼을 비교하는 연구는 제한적이다.

방법 : 이 연구에서는 2019년에서 2020년 사이에 단일공 로봇 담낭절제술을 받은 환자가 등록되었다. 환자 인구 통계, 수술 중 요인, 수술 후 합병증, 수술 후 통증을 일대일 성향 점수 매칭을 사용하여 비교하였다.

결과 : Xi로 단일공 로봇 담낭절제술을 시행받은 환자는 258명, SP로 시행받은 환자는 72명이었다. 일대일 성향 점수 매칭 후 콘솔에서의 수술시간 (Xi 26.3 vs SP 19.6분, $p = 0.015$)과 수술 후 통증 (Xi 6.1 vs SP 4.9, $p < 0.001$)은 SP 그룹에서 유의하게 낮았지만, 총 수술시간 (Xi 48.9 vs SP 45.7분, $p = 0.323$)과 수술 후 합병증 (Xi 0.0% vs. SP 0.0%, $p > 0.999$)은 차이가 없었다. SP 그룹은 더 많은 추정 혈액 손실을 보였다 (Xi 10.6 vs. SP 18.1ml, $p = 0.049$).

결론 : 통계적 차이에도 불구하고 임상적 이점은 유의하지 않았다. 두 플랫폼 모두 SIRC를 수행하는 데 안전하고 실현 가능하지만, 외과 의사의 작업 부하 및 인체 공학을 포함한 추가 조사가 전향적 연구의 형태로 필요하다.

주요어 : 담낭절제술, 다빈치 SP, 다빈치 Xi, 로봇 수술
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		Before PSM				After PSM			
		Total (n=330)	Da Vinci Xi (n=258)	Da Vinci SP (n=72)	p−value	Total (n=106)	Da Vinci Xi (n=53)	Da Vinci SP (n=53)	p−value
Age, mean (SD), year		47.0 (12.3)	48.4 (12.2)	42.2 (11.6)	<0.001	45.4 (11.6)	47.0 (11.6)	43.9 (11.5)	0.168
Sex (male), no. (%)		115 (34.8)	96 (37.2)	19 (26.4)	0.118	31 (29.2)	14 (26..4)	17 (32.1)	0.522
BMI, mean (SD), kg/m^2		24.2 (3.7)	24.0 (3.4)	24.7 (4.5)	0.238	24.6 (4.2)	24.2 (4.0)	25.0 (4.5)	0.348
Smoking history, no. (%)		40 (12.1)	26 (10.1)	14 (19.4)	0.051	15 (14.2)	5 (9.4)	10 (18.9)	0.164
Hypertension, no. (%)		46 (13.9)	38 (14.7)	8 (11.1)	0.554	14 (13.2)	8 (15.1)	6 (11.3)	0.566
DM, no. (%)		23 (7.0)	19 (7.4)	4 (5.6)	0.786	8 (7.5)	4 (7.5)	4 (7.5)	>0.999
COPD, no. (%)		0 (0.0)	0 (0.0)	0 (0.0)	>0.999	0 (0.0)	0 (0.0)	0 (0.0)	>0.999
ASA score, no. (%)	1	146 (44.1)	106 (41.1)	40 (55.6)	0.165	65 (61.3)	36 (67.9)	29 (54.7)	0.163
	2	179 (54.2)	148 (57.4)	31 (43.1)		41 (38.7)	17 (32.1)	24 (45.3)	
	3	5 (1.5)	4 (1.6)	1 (1.4)		0 (0.0)	0 (0.0)	0 (0.0)	
Previous abdominal surgery, no. (%)		88 (26.7)	68 (26.4)	20 (27.8)	0.928	30 (28.3)	18 (34.0)	12 (22.6)	0.196
Preoperative mean albumin level (SD), g/dL		4.5 (0.4)	4.5 (0.3)	4.3 (0.5)	0.006	4.4 (0.3)	4.3 (0.3)	4.5 (0.3)	0.002
Preoperative mean total bilirubin level (SD), mg/dL		0.8 (0.5)	0.8 (0.4)	0.9 (0.6)	0.086	0.7 (0.3)	0.6 (0.2)	0.8 (0.4)	0.002
Presence of symptom, no. (%)		149 (45.2)	96 (37.2)	53 (73.6)	<0.001	54 (50.9)	19 (35.2)	35 (66.0)	0.002
Preoperative acute cholecystitis, no. (%)		27 (8.2)	4 (1.6)	23 (31.9)	<0.001	8 (7.5)	4 (7.5)	4 (7.5)	>0.999
Preoperative CBD stone removal, no. (%)		9 (2.7)	8 (3.1)	1 (1.4)	0.704	0 (0.0)	0 (0.0)	0 (0.0)	>0.999
Preoperative radiologic diagnosis, no. (%)	Stone	168 (50.9)	130 (50.4)	38 (52.8)	<0.001	63 (59.4)	26 (49.1%)	37 (69.8%)	0.053
	Polyp	76 (23.0)	72 (27.9)	4 (5.6)		18 (17.0)	14 (26.4%)	4 (7.5%)	
	Adenomyomatosis	25 (7.6)	23 (8.9)	2 (2.8)		5 (4.7)	3 (5.7%)	2 (3.8%)	
	Cholecystitis	61 (18.5)	33 (12.8)	28 (38.9)		20 (18.9)	10 (18.9)	10 (18.9)	

PSM, propensity score matching; SD, standard deviation; BMI, body mass index; DM, diabetes mellitus; COPD, chronic obstructive pulmonary disease; ASA, American Society of Anesthesiologist; CBD, common bile duct

Table 1. Preoperative information of patients; before and after PSM

	Before PSM				After PSM			
	Total (n=330)	Da Vinci Xi (n=258)	Da Vinci SP (n=72)	p−value	Total (n=106)	Da Vinci Xi (n=53)	Da Vinci SP (n=53)	p−value
Time of operation, mean (SD), min	43.9 (15.4)	43.4 (16.2)	45.9 (12.0)	0.155	47.3 (16.6)	48.9 (20.1)	45.7 (12.2)	0.323
Operation time at console, mean (SD), min	22.5. (12.1)	23.1 (13.3)	20.3 (5.8)	0.018	23.1 (13.5)	26.3 (17.5)	19.5 (5.3)	0.015
Estimated blood loss, mean (SD), mL	15.4 (23.0)	14.3 (24.8)	19.2 (14.1)	0.031	14.3 (19.7)	10.6 (24.1)	18.1 (13.2)	0.049
RBC transfusion, no. (%)	0 (0.0)	0 (0.0)	0 (0.0)	>0.999	0 (0.0)	0 (0.0)	0 (0.0)	>0.999
Insertion of drainage, no. (%)	3 (0.9)	1 (0.4)	2 (2.8)	0.235	1 (0.9)	0	1 (1.9)	0.315
Postoperative pain control, no. (%) Injection	329 (99.7)	257 (99.6)	72 (100.0)	>0.999	105 (99.1)	52 (98.1)	53 (100)	0.315
PO	1 (0.3)	1 (0.4)	0 (0.0)		1 (0.9)	1 (1.9)	0 (0.0)	
Injection of analgesic, no. (SD)	3.8 (1.0)	4.0 (1.0)	3.2 (0.6)	<0.001	3.4 (0.9)	3.7 (1.0)	3.1 (0.6)	0.001
NRS at day of operation, mean (SD)	5.5 (1.6)	5.7 (1.6)	4.9 (1.2)	<0.001	5.5 (1.5)	6.1 (1.6)	4.9 (1.2)	<0.001
NRS at POD 1, mean (SD)	3.6 (1.8)	4.3 (1.4)	1.3 (1.2)	<0.001	2.7 (2.0)	4.3 (1.4)	1.2 (1.1)	<0.001
Complication, no. (%)	2 (0.6)	2 (0.8)	0 (0.0)	>0.999	0 (0.0)	0 (0.0)	0 (0.0)	>0.999
Postoperative stay, no. (%)	1.4 (0.7)	1.1 (0.3)	2.3 (0.7)	<0.001	1.7 (0.8)	1.1 (0.3)	2.3 (0.7)	<0.001
Transfer after discharged, no. (%)	0 (0.0)	0 (0.0)	0 (0.0)	>0.999	0 (0.0)	0 (0.0)	0 (0.0)	>0.999
Unexpected readmission, no. (%)	4 (1.2)	4 (1.6)	0 (0.0)	0.65	1 (0.9)	0	1 (1.9)	0.315

PSM, propensity score matching; SD, standard deviation; RBC, red blood cell; PO, per os; NRS, numeric rating scale; POD, postoperative day

Table 2. Postoperative surgical and pain−related outcomes; before and after PSM

	Da Vinci Xi	Costs	Da Vinci SP	Costs
Port	8 mm camera cannula	₩ 2,599	Da Vinci SP cannula, 25 mm x 100 mm	₩ 3,713
	8 mm blunt obturator	₩ 1,040	Da Vinci SP obturator, 25 mm x 100 mm	₩ 743
	5 x 250 mm curved cannula, camera right	₩ 2,599		
	5 x 250 mm curved cannula, camera left	₩ 2,599		
	5 x 250 mm Flexible Blunt Obturator	₩ 1,035		
Instrument	Crocodile grasper	₩ 225,280	Da Vinci SP fenestrated bipolar forceps	₩ 426,910
	Permanent cautery hook	₩ 259,930	Da Vinci SP Maryland bipolar forceps	₩ 426,910
	Medium−large clip applier	₩ 207,900	Da Vinci SP medium−large clip applier	₩ 297,000
	Curved scissors	₩ 247,500	Da Vinci SP monopolar curved scissors	₩ 309,375
			Da Vinci SP Cadiere forceps	₩ 340,300
etc	Arm drape	₩ 285,285	Instrument arm drape	₩ 512,600
	Monopolar energy instrument cord	₩ 16,665	EnergyShield monopolar cautery cord	₩ 16,665
Total		₩ 1,252,433		₩ 2,334,215

Table 3. The costs of robotic instruments and accessories used in Da Vinci Xi and Da Vinci SP

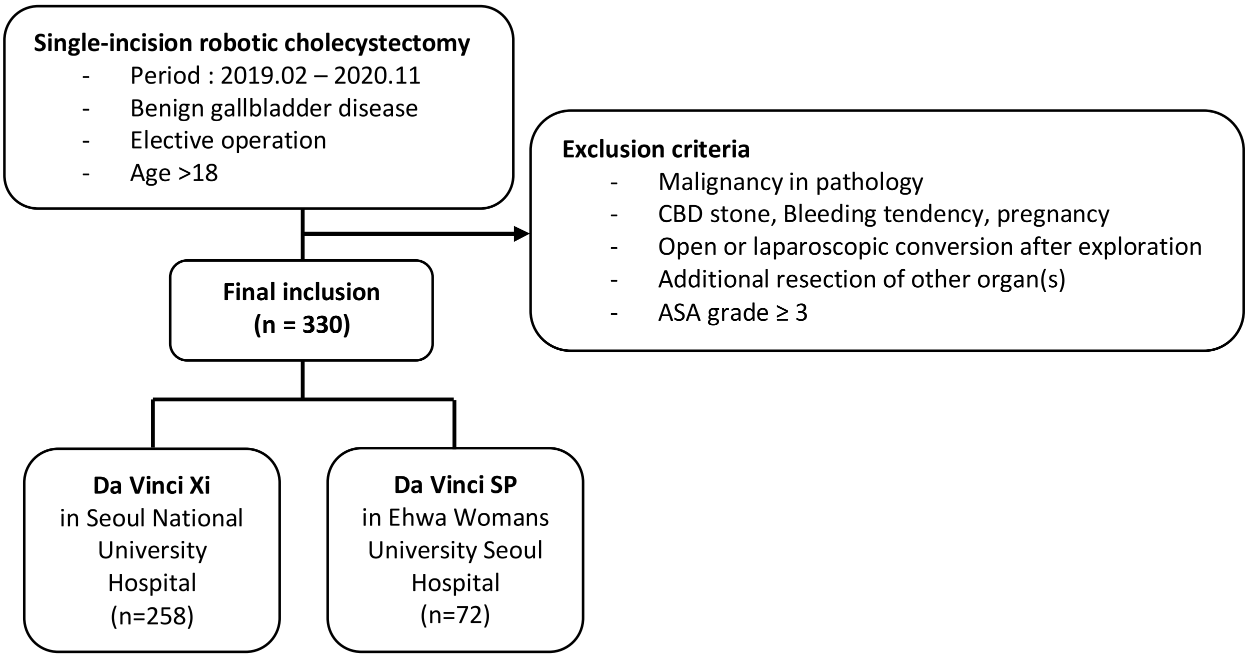
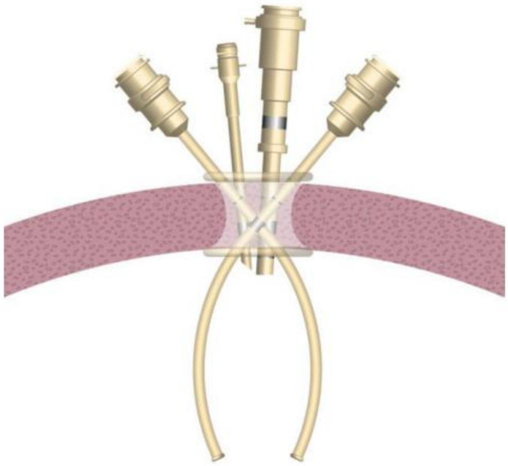


Figure 1. Study flow diagram

A.



B.

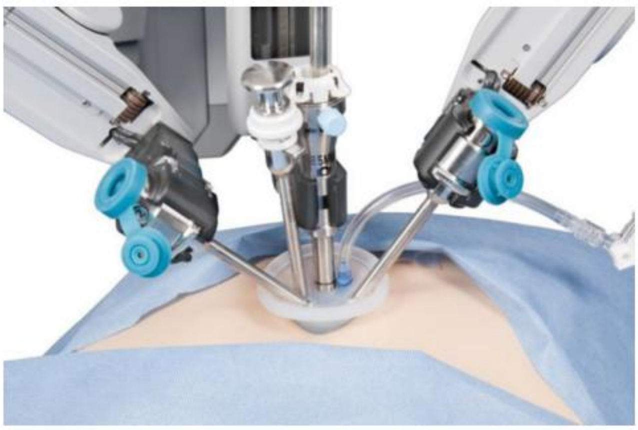


Figure 2. Da Vinci Xi with crossover technique. A. The multi−arms bend flexibly as they pass through the umbilical single incision enabling easier movements of instruments. B. Extracorporeal view of da Vinci Xi during operation.

Figure 3. Da Vinci SP system, specialized for single−incision surgery. SP is characterized by a single arm that has three different instruments and camera inside it