pISSN: 2508-5778 • eISSN: 2508-5859
Ann Hepatobiliary Pancreat Surg 2025;29:140-149
https://doi.org/10.14701/ahbps.24-198

AHBPS
Annals of Hepato-Biliary-Pancreatic Surgery

Original Article

Comparative analysis of postoperative outcomes of single-incision cholecystectomy: Propensity score matching of robotic surgery using the da Vinci SP system and da Vinci Xi system vs. laparoscopic surgery

Jeong-Ik Park[1], Yong-Kyu Chung[2], Young Min Lee[1], Chang Woo Nam[1], Yang Won Nah[1]

[1]Department of Surgery, Ulsan University Hospital, University of Ulsan College of Medicine, Ulsan, Korea,
[2]Department of Surgery, Inje University Haeundae Paik Hospital, Inje University College of Medicine, Busan, Korea

Backgrounds/Aims: We compared the postoperative outcomes of single-incision laparoscopic cholecystectomy (SILC) with those of single-incision robotic cholecystectomy (SIRC) using the da Vinci Xi and SP systems.

Methods: We retrospectively analyzed data from 206 patients who underwent these procedures by a single surgeon between August 2020 and April 2022. Propensity score matching was used to adjust for confounders and evaluate outcomes.

Results: SILC exhibited shorter operation times compared to SIRC with Xi and SP (44.9 ± 14.5 min vs. 55.3 ± 12.2 min vs. 55.2 ± 16.2 min, $p < 0.001$). SIRC with Xi had shorter docking times (6.2 ± 2.8 min vs. 10.3 ± 2.3 min, $p < 0.001$), while SIRC with SP demonstrated reduced console times (11.2 ± 2.4 min vs. 18.6 ± 8.0 min, $p < 0.001$). Pain scores and complications did not significantly differ between the groups.

Conclusions: Both SILC and SIRC showed comparable outcomes, with the SP system providing advantages such as reduced console time and fully articulated arms, likely reducing surgeon stress.

Key Words: Cholecystectomy; Single-incision; Laparoscopy; Robotic

INTRODUCTION

The adoption of single-incision laparoscopic cholecystectomy (SILC) has expanded due to benefits such as reduced postoperative pain and enhanced cosmetic outcomes. Nevertheless, it faces limitations including instrument collisions and poor ergonomics resulting from the narrow surgical window. These challenges are efficiently addressed by robotic systems with superior ergonomics [1-5]. The da Vinci Xi system features excellent ergonomics and was adopted for single-incision robotic cholecystectomy (SIRC); however, its semi-rigid arm design through a single port poses certain difficulties. The da Vinci SP system, a newer platform, includes three fully wristed and elbowed instruments along with a flexible camera, effectively mitigating these challenges [6-9]. This study aims to compare the postoperative outcomes of SILC and SIRC using the da Vinci Xi and SP systems.

Received: October 11, 2024, **Revised:** December 9, 2024,
Accepted: December 16, 2024, **Published online:** January 20, 2025

Corresponding author: Jeong-Ik Park, MD, PhD
Department of Surgery, Ulsan University Hospital, University of Ulsan College of Medicine, 25, Daehakbyeongwon-ro, Dong-gu, Ulsan 44033, Korea
Tel: +82-52-250-7109, Fax: +82-52-250-7350, E-mail: jipark@uuh.ulsan.kr
ORCID: https://orcid.org/0000-0002-1986-9246

MATERIALS AND METHODS

Patient selection

We retrospectively reviewed the medical records of 206 patients who underwent single-incision cholecystectomy by a single surgeon using SILC and SIRC with da Vinci Xi and SP systems across two institutions from August 2020 to April 2022. Of these, 126 underwent SILC, 30 underwent SIRC with the da Vinci Xi system, and 50 underwent SIRC with the da Vinci SP system.

Between August 13, 2020, and February 20, 2021, 91 patients underwent SILC and 27 underwent SIRC using the da Vinci Xi system at Haeundae Paik Hospital.

Additionally, between March 1, 2021, and April 30, 2022, SILC was performed on 35 patients, SIRC using the da Vinci Xi system on three patients, and SIRC with the da Vinci SP system on 50 patients at Ulsan University Hospital, following the author's relocation.

The patient selection criteria for single-incision cholecystectomy included outpatients with a body mass index of ≤ 35 suffering from benign gallbladder diseases. The patients were informed about both robotic and laparoscopic surgical options, enabling them to select the preferred method. At Ulsan University Hospital, SILC was conducted only when a flexible scope was available. Initially, the da Vinci Xi system was employed for robotic surgery in three patients, after which the da Vinci SP system was used exclusively. Cases with prior upper abdominal surgery (such as stomach surgery), suspected malignancy, or severe acute cholecystitis (Tokyo guideline grade III) [10] were excluded from all three surgical approaches.

This retrospective study received approval from the institutional review boards (IRBs) of Ulsan University Hospital (UUH 2023-09-005-001) and Haeundae Paik Hospital (HPIRB 2023-10-008). All methods were carried out in accordance with relevant guidelines and regulations. The study conformed to the Declaration of Helsinki, and the need for written informed consent was waived due to its retrospective nature.

Operative procedures

Single-incision laparoscopic cholecystectomy

Under general anesthesia, the patient is positioned in the supine split-leg (French) position. Access to the peritoneal cavity is gained through a 2.5-cm transumbilical incision using an open approach, followed by the insertion of a single-port access device (Lapsingle Vision®; Sejong Medical). The pneumoperitoneum is maintained at a pressure of 15 mmHg, and the patient is then placed in the reverse Trendelenburg position with a 30-degree left tilt. Visualization is facilitated by the first assistant using a flexible laparoscope (Endoeye Flex HD®, Olympus), while the second assistant grasps the gallbladder fundus with forceps and retracts the liver to fully expose Calot's triangle (Fig. 1A). Positioned between the patient's legs, the operator dissects and secures the cystic duct and artery with hemoclips or Hem-O-Lok® (Teleflex Medical) (Fig. 1B). Following this, the gallbladder is carefully dissected from the liver bed to ensure adequate hemostasis and is then removed through the umbilical single-port site. To minimize the risk of an incisional hernia, the fascia is carefully undermined and meticulously closed using absorbable polyglactin interrupted sutures for the fascial layer and subcuticular sutures for the skin (Fig. 1C).

Single-incision robotic cholecystectomy using the da Vinci Xi system

The initial steps of SIRC using the da Vinci Xi system are the same as those of SILC, except that the patient is positioned supine during the insertion of the single-port access device (Lapsingle Vision®, Sejong Medical), creation of pneumoperitoneum, and positioning. The da Vinci Xi system is docked at the patient's right upper quadrant. A single straight robotic cannula is utilized for camera insertion at the midline of the single port, while two curved cannulas are placed on the single port's left and right sides, forming a crossed configuration (Fig. 2A). The hook is deployed through the left cannula, and a grasper is deployed through the right cannula. As the left and right sides are recognized as crossed by the da Vinci Xi system, the surgeon's right hand operates the hook deployed through the left cannula, and the left hand operates the grasp-

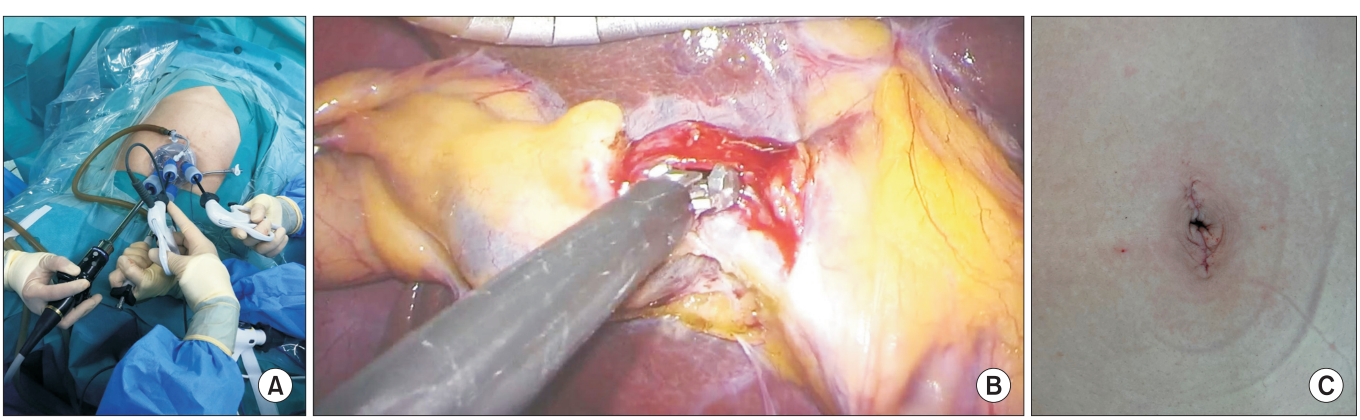

Fig. 1. Single-incision laparoscopic cholecystectomy. (A) The first assistant uses a flexible laparoscope, while the second assistant uses forceps to grasp the gallbladder fundus and a snake retractor to retract the liver. Positioned between the patient's legs, the operator employs a single instrument. (B) The second assistant performs gallbladder traction and liver retraction to fully expose Calot's triangle. (C) A 2.5-cm skin incision is made at the umbilicus.

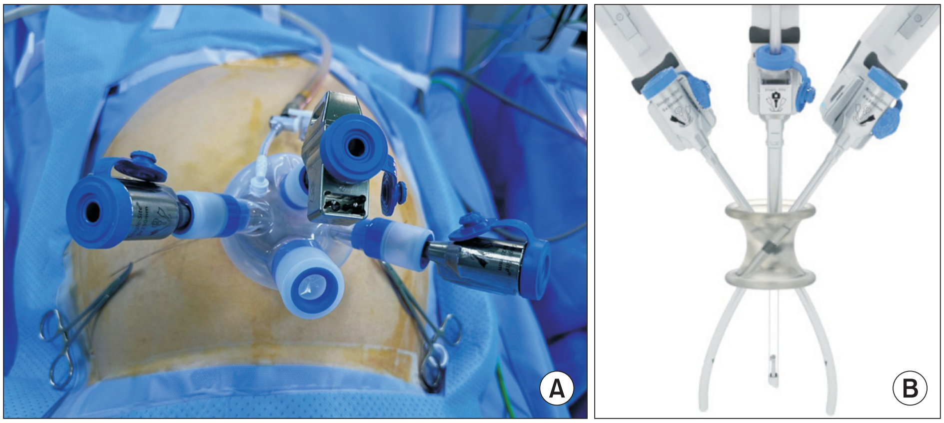

Fig. 2. Single-port access device of the da Vinci Xi system. (A, B) A straight robotic cannula for the camera is positioned in the midline of the single port, flanked by two curved cannulas on each side in a crossed configuration.

er deployed through the right cannula (Fig. 2B). The assistant retracts the gallbladder's fundus through the remaining trocar hole of the single port using grasping forceps. The operator, grasping the gallbladder body with the grasper in the left hand, exposes Calot's triangle, allows for the dissection and ligation of the cystic duct and artery using Hem-O-Lok® (Teleflex Medical). The gallbladder is then dissected from the liver bed and closure is carried out using the technique previously described for SILC.

Single-incision robotic cholecystectomy using the da Vinci SP system

During SIRC employing the da Vinci SP system, the patient remains supine. The insertion method for the single-port access device mirrors that used for SILC and SIRC with the da Vinci Xi system. In this procedure, a 3.0-cm transumbilical incision is made for the single-port access device (Lapsingle Vision SP®, Sejong Medical). Following pneumoperitoneum establishment, the entry guide cannula is inserted. The system is then docked in the reverse Trendelenburg position with a 30-degree left tilt (Fig. 3A). The camera is inserted through the upper hole of the entry guide cannula. Fenestrated bipolar for-

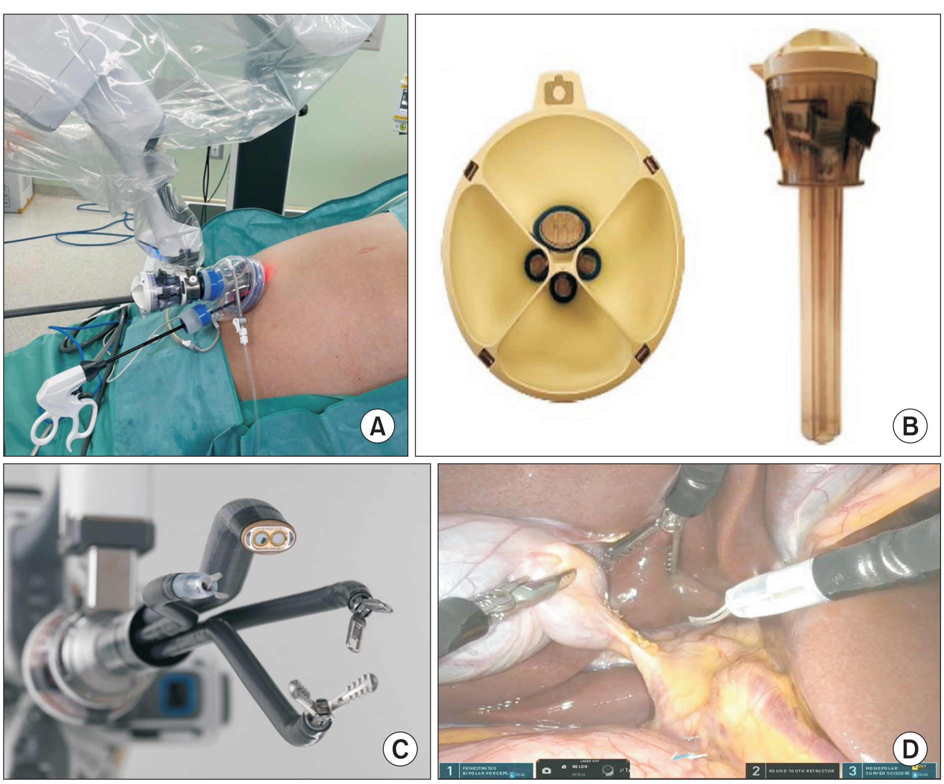

Fig. 3. Single-incision robotic cholecystectomy using the da Vinci SP system. (A) The da Vinci SP platform is docked to the entry guide cannula. (B) The entry guide cannula features four openings; the upper opening accommodates the camera, the left opening houses the fenestrated bipolar forceps (arm 1), the lower opening supports the round tooth retractor (arm 2), and the right opening is designated for the monopolar curved scissors (arm 3). (C) The da Vinci SP system comprises one flexible camera and three robotic arms, each equipped with two joints. (D) The operational field with the da Vinci SP system provides optimal exposure of Calot's triangle, akin to that achieved in single-incision laparoscopic cholecystectomy with assistance from two assistants.

https://doi.org/10.14701/ahbps.24-198

ceps are placed in the left hole (arm 1), a round tooth retractor in the lower hole (arm 2), and monopolar curved scissors in the right hole (arm 3) (Fig. 3B, 3C). Arm 1 is utilized to exert traction on Hartmann's pouch of the gallbladder, while arm 2 retracts the liver to fully expose Calot's triangle. Arm 3's scissors, energized by a monopolar source, isolate the cystic duct and artery, achieving a critical view of safety (Fig. 3D). Hem-O-lok® clips (Teleflex Medical) are then used to secure and transect the cystic duct and artery. The gallbladder is dissected from the liver bed, with closure carried out using the previously described technique for SILC.

Assessment of degree of postoperative pain

To evaluate the degree of postoperative pain, a numeric rating scale (NRS) was utilized immediately following surgery, on the morning of the first postoperative day, and just prior to discharge.

Statistical analysis

Categorical variables were compared between groups using the chi-square test for unmatched patients and the McNemar test (or marginal homogeneity test) for matched patients. For continuous variables, comparisons were made using Student's t-test for unmatched patients and the paired t-test for matched patients. To address potential biases from varying covariate distributions among patients across the three groups, propensity score matching (PSM) analysis was performed using a 1-to-1 nearest neighbor matching method with a caliper size of 0.2. Covariate balance in the matched groups was evaluated by calculating the standardized mean differences, which were all less than 0.20. Statistical significance was established at $p < 0.05$. All statistical analyses were carried out using SPSS (version 24.0; IBM Corp.).

RESULTS

We compared the basic characteristics of the patients in the SILC, da Vinci Xi system, and da Vinci SP system groups (Table 1). The ages (50.2 ± 14.8 years, 46.9 ± 11.7 years, and 47.7 ± 8.6 years in the SILC, da Vinci Xi system, and da Vinci SP sys-

Table 1. Baseline patient characteristics

	SILC (n = 126)	Xi (n = 30)	SP (n = 50)	*p*-value
Age (yr)	50.2 ± 14.8	46.9 ± 11.7	47.7 ± 8.6	0.329
Sex				0.984
Male	49 (38.9)	12 (40.0)	19 (38.0)	
Female	77 (61.1)	18 (60.0)	31 (62.0)	
BMI (kg/m^2)	24.1 ± 3.6	24.2 ± 3.2	24.5 ± 3.3	0.803
ASA classification				< 0.001
I	16 (12.7)	17 (56.7)	0 (0.0)	
II	101 (80.2)	12 (40.0)	48 (96.0)	
III	9 (7.1)	1 (3.3)	2 (4.0)	
IV	0 (0.0)	0 (0.0)	0 (0.0)	
Abdominal surgery history	23 (18.3)	4 (13.3)	9 (19.1)	0.784
Diagnosis				< 0.001
Polyp	15 (11.9)	12 (40.0)	7 (14.0)	
Adenomyomatosis	4 (3.2)	0 (0.0)	7 (14.0)	
Stone/chronic cholecystitis	104 (82.5)	18 (60.0)	36 (72.0)	
Acute cholecystitis	3 (2.4)	0 (0.0)	0 (0.0)	
Preoperative CBD stone(ERCP)	12 (9.5)	1 (3.3)	1 (2.0)	0.145
Symptomatic	65 (51.6)	9 (30.0)	25 (50.0)	0.099
Preoperative lab				
Total bilirubin (mg/dL)	0.9 ± 0.9	0.7 ± 0.3	0.5 ± 0.2	0.009
AST (IU/L)	44.5 ± 28.4	29.5 ± 11.1	21.7 ± 9.9	< 0.001
ALT (IU/L)	48.8 ± 56.6	28.5 ± 15.5	25.2 ± 24.1	0.004
Albumin (g/dL)	4.0 ± 0.4	4.1± 0.4	4.5 ± 0.2	< 0.001
WBC ($\times 10^3$/L)	6,264.8 ± 1,719.9	6,132.0 ± 1,408.7	6,228.4 ± 1,641.4	0.925
CRP (mg/dL)	0.4 ± 1.4	0.2 ± 0.3	0.1 ± 0.2	0.233

Values are presented as mean ± standard deviation or number (%).
SILC, single-incision laparoscopic cholecystectomy; BMI, body mass index; ASA, American Society of Anesthesiologist; CBD, common bile duct; ERCP, endoscopic retrograde cholangiopancreatography; AST, aspartate transaminase; ALT, alanine transaminase; WBC, white blood cell; CRP, C-reactive protein.

tem groups, respectively) did not show significant differences across these groups ($p = 0.329$). Similarly, sex distribution did not differ significantly among the groups. Additionally, the body mass index values (24.1 ± 3.6, 24.2 ± 3.2, and 24.5 ± 3.3 in the SILC, da Vinci Xi system, and da Vinci SP system groups, respectively) were not statistically different among these groups ($p = 0.803$). Most patients had an American Society of Anesthesiologists classification of II or lower, encompassing 117 (92.9%) patients in the SILC group, 29 (96.7%) in the da Vinci Xi system group, and 48 (96.0%) in the da Vinci SP system group. Only three patients in the SILC group presented with acute cholecystitis, all of whom were classified as Tokyo guideline grade I (mild). Statistical analysis of preoperative blood tests revealed significant differences in levels of total bilirubin, aspartate transaminase, alanine transaminase, and albumin; however, these differences were not clinically significant.

After applying a 1 : 1 PSM, we observed a significant difference in the C-reactive protein levels between the SILC and da Vinci Xi system groups; yet, this difference was not clinically significant (Table 2). No significant differences in the basic characteristics were found between the da Vinci SP system and SILC groups after applying the 1:1 PSM (Table 3).

The operative and postoperative outcomes by surgery type are presented in Table 4. Total operative time differed significantly among the SILC, da Vinci Xi system, and da Vinci SP system groups (44.9 ± 14.5 minutes, 55.3 ± 12.2 minutes, and 55.2 ± 16.2 minutes, respectively; $p < 0.001$). The docking time for the da Vinci Xi group was significantly shorter than that for the da Vinci SP system group (6.2 ± 2.8 minutes vs 10.3 ± 2.3 minutes; $p < 0.001$), whereas the console time for the da Vinci SP system group was significantly shorter than for the da Vinci Xi system group (11.2 ± 2.4 minutes vs 18.6 ± 8.0 minutes; $p < 0.001$). There was no statistically significant difference in gallbladder perforation rates during manipulation among the SILC, da Vinci Xi system, and da Vinci SP system groups (4.8%, 6.7%, and 12.0%, respectively). Postoperative drainage tube placement was performed only in cases with concerns of bleeding or bile leak from the gallbladder bed (five cases in the SILC group and one case in the da Vinci SP system group; no significant difference).

In the two SIRC groups, surgical conversion was not performed; however, it was required for one patient in the SILC

Table 2. Comparison of patient characteristics between Xi and single-incision laparoscopic cholecystectomy (before and after propensity score matching)

	Before PSM				After PSM			
	Xi (n=30)	SILC (n=126)	SMD	*p*-value	Xi (n=24)	SILC (n=24)	SMD	*p*-value
Age (yr)	46.9 ± 11.7	50.2 ± 14.8	0.2757	0.268	47.0 ± 11.1	46.3 ± 14.8	–0.063	0.861
Sex			0.0227	0.911			–0.085	> 0.999
Male	12 (40.0)	49 (38.9)			10 (41.7)	11 (45.8)		
Female	18 (60.0)	77 (61.1)			14 (58.3)	13 (54.2)		
BMI (kg/m^2)	24.2 ± 3.2	24.1 ± 3.6	–0.0195	0.931	24.1 ± 2.74	23.4 ± 3.2	–0.259	0.479
ASA classification			0.8362	< 0.001			–0.071	> 0.999
I	17 (56.7)	16 (12.7)			12 (50.0)	12 (50.0)		
II	12 (40.0)	101 (0.2)			11(45.8)	12 (50.0)		
III	1 (3.3)	9 (7.1)			1 (4.2)	0 (0.0)		
IV	0 (0.0)	0 (0.0)			0 (0.0)	0 (0.0)		
Abdominal surgery history	4 (13.3)	23 (18.3)	0.1448	0.522	3 (12.5)	3 (12.5)	0.000	> 0.999
Acute cholecystitis	0 (0.0)	3 (2.4)	0.0238	> 0.999	0 (0.0)	0 (0.0)	NA	NA
Preoperative CBD	1 (3.3)	12 (9.5)	0.3449	0.465	1 (4.2)	0 (0.0)	–0.209	> 0.999
Stone (E RCP)								
Symptomatic	9 (30.0)	65 (51.6)	0.4711	0.033	8 (33.3)	9 (37.5)	0.088	> 0.999
Preoperative lab								
Total bilirubin (mg/dL)	0.7 ± 0.3	0.9 ± 0.9	0.4927	0.307	0.7 ± 0.4	0.7 ± 0.4	–0.090	0.758
AST (IU/L)	29.5 ± 11.1	44.5 ± 28.4	1.3449	< 0.001	31.7 ± 11.3	33.2 ± 14.7	0.132	0.665
ALT (IU/L)	28.5 ± 15.5	48.8 ± 56.6	1.3074	0.001	28.3 ± 12.8	30.0 ± 18.5	0.133	0.577
Albumin (g/dL)	4.1 ± 0.4	4.0 ± 0.4	–0.2060	0.316	4.1 ± 0.4	4.1 ± 0.3	–0.067	0.800
WBC (×10^3/L)	6,132.0 ± 1,408.7	6,264.8 ± 1,719.9	0.0943	0.695	6,008.7 ± 1,461.7	6,239.1 ± 1,345.5	0.158	0.542
CRP (mg/dL)	0.2 ± 0.3	0.4 ± 1.4	0.5494	0.529	0.3 ± 0.4	0.1 ± 0.1	–0.447	0.043

Values are presented as mean ± standard deviation or number (%).
PSM, propensity score matching; SILC, single-incision laparoscopic cholecystectomy; SMD, standardized mean difference; BMI, body mass index; ASA, American Society of Anesthesiologist; CBD, common bile duct; ERCP, endoscopic retrograde cholangiopancreatography; AST, aspartate transaminase; ALT, alanine transaminase; WBC, white blood cell; CRP, C-reactive protein; NA, not available.

Table 3. Comparison of patient characteristics between SP and single-incision laparoscopic cholecystectomy (before and after propensity score matching)

	Before PSM				After PSM			
	SP (n = 50)	SILC (n = 126)	SMD	*p*-value	SP (n = 35)	SILC (n = 35)	SMD	*p*-value
Age (yr)	47.7 ± 8.6	50.2 ± 14.8	0.2906	0.166	48.0 ± 8.7	48.8 ± 11.7	0.0948	0.754
Sex			–0.4827	0.008			0.0591	> 0.999
Male	19 (38.0)	49 (38.9)			13 (37.1)	12 (34.3)		
Female	31 (62.0)	77 (61.1)			22 (62.9)	23 (65.7)		
BMI (Kg/m^2)	24.5 ± 3.3	24.1 ± 3.6	–0.1179	0.516	24.6 ± 3.2	24.3 ± 3.1	–0.1023	0.664
ASA classification			–0.4827	0.008			0.000	0.918
I	0 (0.0)	16 (12.7)			0 (0)	2 (5.7)		
II	48 (96.0)	101 (0.2)			34 (97.1)	30 (85.7)		
III	2 (4.0)	9 (7.1)			1 (2.9)	3 (8.6)		
IV	0 (0.0)	0 (0.0)			0 (0.0)	0 (0.0)		
Abdominal surgery history	9 (19.1)	23 (18.3)	0.0066	0.893	6 (18.8)	7 (20.0)	0.758	> 0.999
Acute cholecystitis	0 (0.0)	3 (2.4)	0.0238	0.559	0 (0.0)	0 (0.0)	NA	NA
Preoperative CBD Stone (ERCP)	1 (2.0)	12 (9.5)	0.0317	0.113	1 (2.9)	1 (2.9)	0.000	> 0.999
Symptomatic	25 (50.0)	65 (51.6)	0.5374	0.849	16 (45.7)	15 (42.9)	–0.0574	> 0.999
Preoperative lab								
Total bilirubin (mg/dL)	0.5 ± 0.2	0.9 ± 0.9	1.6106	< 0.001	0.5 ± 0.2	0.6 ± 0.3	0.2577	0.341
AST (IU/dL)	21.7 ± 9.9	44.5 ± 28.4	2.2825	< 0.001	23.7 ± 10.8	22.8 ± 13.1	–0.0873	0.766
ALT (IU/L)	25.2 ± 24.1	48.8 ± 56.6	0.9802	< 0.001	28.8 ± 27.8	30.8 ± 54.2	0.0749	0.849
Albumin (g/dL)	4.5± 0.2	4.0 ± 0.4	–1.8475	< 0.001	4.5 ± 0.2	4.5 ± 0.2	0.0000	> 0.999
WBC (×10^3/L)	6,228.4 ± 1,641.4	6,264.8 ± 1,719.9	0.0222	0.898	6,092.0 ± 1,736.3	5,988.8 ± 1,547.7	–0.0594	0.776
CRP (mg/dL)	0.1 ± 0.2	0.4 ± 1.4	1.1800	0.020	0.1 ± 0.3	0.1 ± 0.1	–0.1395	0.475

Values are presented as mean ± standard deviation or number (%).
PSM, propensity score matching; SILC, single-incision laparoscopic cholecystectomy; SMD, standardized mean difference; BMI, body mass index; ASA, American Society of Anesthesiologist; CBD, common bile duct; ERCP, endoscopic retrograde cholangiopancreatography; AST, aspartate transaminase; ALT, alanine transaminase; WBC, white blood cell; CRP, C-reactive protein; NA, not available.

Table 4. Surgical and postoperative outcomes by procedure type (before and after propensity score matching)

	SILC (n = 126)	Xi (n = 30)	SP (n = 50)	*p*-value	Xi (n = 24)	SILC (n = 24)	*p*-value	SP (n = 35)	SILC (n = 35)	*p*-value
Operation time (min)	44.9 ± 14.5	55.3 ± 12.2	55.2 ± 16.2	< 0.001	56.4 ±13.3	46.6 ±16.5	0.029	56.4 ±13.3	48.4 ±14.8	0.036
Docking time (min)	NA	6.2 ± 2.8	10.3 ± 2.3	< 0.001	NA	NA	NA	NA	NA	NA
Console time (min)	NA	18.6 ± 8.0	11.2 ± 2.4	< 0.001	NA	NA	NA	NA	NA	NA
Intraoperative GB perforation	6 (4.8)	2 (6.7)	6 (12.0)	0.227	2 (8.3)	2 (8.3)	> 0.999	4 (11.4)	0 (0.0)	0.114
Estimated blood loss (mL)	25.4 ± 22.3	34.0 ± 17.2	22.0 ± 71.1	0.420	33.7 ± 17.8	25.4 ± 14.8	0.085	28.2 ± 84.4	12.2 ± 11.8	0.275
Transfusion	0 (0.0)	0 (0.0)	0 (0.0)	-	0 (0.0)	0 (0.0)	NA	0 (0.0)	0 (0.0)	NA
JP drain insertion	5 (4.0)	0 (0.0)	1 (2.0)	0.462	0 (0.0)	0 (0.0)	NA	1 (2.9)	0 (0.0)	NA
conversion	1 (0.8)	0 (0.0)	0 (0.0)	0.727	0 (0.0)	0 (0.0)	NA	0 (0.0)	0 (0.0)	NA
complication	2 (1.6)	0 (0.0)	0 (0.0)	0.527	0 (0.0)	0 (0.0)	NA	0 (0.0)	0 (0.0)	NA
Hospital stay (day)	3.2 ± 6.0	2.4 ± 0.6	2.4 ± 0.8	0.481	2.4 ± 0.5	2.6 ± 0.9	0.356	2.6 ± 1.0	2.4 ± 1.1	0.37

Values are presented as mean ± standard deviation or number (%).
SILC, single-incision laparoscopic cholecystectomy; GB, gallbladder; JP, Jackson-Pratt; NA, not available.

group due to difficulty in achieving a critical view of safety because of inflammation, necessitating the insertion of an additional 5-mm trocar. Regarding postoperative complications, one case each of postoperative pneumonia and ileus occurred in the SILC group. The hospital length of stay was not significantly different among the SILC, da Vinci Xi system, and da Vinci SP system groups (3.2 ± 6.0 days, 2.4 ± 0.6 days, and 2.4 ± 0.8 days, respectively).

Table 5. Postoperative pain by surgical procedure (before and after propensity score matching)

	SILC (n = 126)	Xi (n = 30)	SP (n = 50)	*p*-value	Xi (n = 24)	SILC (n = 24)	*p*-value	SP (n = 35)	SILC (n = 35)	*p*-value
Postoperative PCA	93 (73.8)	27 (90.0)	21 (42.0)	< 0.001	21 (87.5)	18 (75.0)	0.461	16 (45.7)	15 (42.9)	0.810
NRS										
Operation day	6.3 ± 1.6	5.5 ± 1.3	5.9 ± 2.4	0.096	5.4 ± 1.2	6.1 ± 1.9	0.161	5.8 ±2.5	6.1 ±2.1	0.582
Postoperative day #1	3.4 ± 0.9	3.4 ± 0.9	3.3 ± 1.3	0.885	3.4 ± 0.9	3.4 ± 0.8	0.874	3.3 ±1.0	3.2 ±1.2	0.754
Discharge day	2.2 ± 0.7	2.2 ± 0.9	2.3 ± 0.8	0.749	2.4 ± 0.7	2.0 ± 0.83	0.055	2.3 ±0.8	2.3 ±0.6	0.749

Values are presented as number (%) or mean ± standard deviation.
SILC, single-incision laparoscopic cholecystectomy; PCA, patient controlled analgesics; NRS, numeric rating scale.

After applying 1 : 1 PSM, the total operative time was the only variable significantly different among groups (da Vinci Xi system vs. SILC: 56.4 ± 13.3 minutes vs 46.6 ± 16.5 minutes, $p = 0.029$; da Vinci SP system vs. SILC: 56.4 ± 13.3 minutes vs 48.4 ± 14.8 minutes, $p = 0.036$) (Table 4).

NRS scores for patient-controlled analgesia and postoperative pain are depicted in Table 5. Significantly fewer patients in the da Vinci SP system group used patient-controlled analgesia compared to SILC and da Vinci Xi system groups (42.0% vs 73.8% vs 90.0%, respectively; $p < 0.001$). There were no significant differences in the NRS scores immediately after surgery, on postoperative day 1, or on the day of discharge. After applying 1 : 1 PSM, no significant differences were observed between groups (Table 5).

Average costs for each surgical procedure were: SILC costed 1,540,298.6 ± 394,264.1 KRW, da Vinci Xi system costed 6,876,126.7 ± 515,470.7 KRW, and da Vinci SP system costed 7,318,030.6 ± 2,106,118.2 KRW. Results indicate that robotic approaches (SIRC) were significantly more expensive than traditional laparoscopic surgery (SILC) (Table 6).

DISCUSSION

SILC is a minimally invasive technique that has achieved widespread acceptance and preference over the traditional multiport approach for cholecystectomy due to its efficacy and reduced invasiveness. The ergonomic challenges associated with laparoscopic surgery have been substantially mitigated with the introduction of single-incision robotic surgery platforms, markedly enhancing surgical convenience [1-4].

Table 6. Cost by surgical procedure

	Cost (₩)
SILC	1,540,298.6 ± 394,264.1
Xi	6,876,126.7 ± 515,470.7
SP	7,318,030.6 ± 2,106,118.2

Values are presented as mean ± standard deviation.
SILC, single-incision laparoscopic cholecystectomy.

Currently, the da Vinci Xi and SP systems are the two primary single-incision platforms for robotic surgery. The author (JI Park) initiated the use of a 3-mm trocar-assisted SILC in 2015. The transition to pure SILC occurred in 2017, facilitated by the introduction of a flexible scope. The adoption of the da Vinci Xi system in 2020 led to its application in SIRC. At Ulsan University Hospital, SIRC began utilizing the da Vinci SP system, which, due to its unparalleled convenience, has since become the exclusive system used, replacing the da Vinci Xi system.

Initially, when SIRC was performed using the da Vinci Xi system, it was found to be considerably more convenient than SILC. A significant advantage was the capability to adjust the camera freely to the desired position and angle without needing a scopist. Although the arms of this system were semi-rigid, the occurrence of instrument collision was minimal, thus simplifying the surgical process compared to laparoscopic procedures. However, additional instruments for tasks such as traction of the gallbladder fundus or liver retraction, and assistance were still required.

In contrast, the da Vinci SP system, equipped with three articulating arms and a flexible camera, offers superior manageability and leads to minimal instrument collisions in single-incision cholecystectomy. Its ergonomic design renders it the most comfortable method for surgeons performing this procedure.

During this study, consistent with previous research [11,12], SIRC exhibited a statistically longer total operative time than SILC due to the docking process. A comparative review of the docking processes between the da Vinci Xi and SP systems revealed that the Xi system requires separate docking for each robotic arm, whereas the SP system benefits from a single entry guide cannula, simplifying the docking to a single step. Contrary to expectations based on previous studies [6,7,9], the SP system demonstrated a longer docking time in this study. This discrepancy may be attributed to the fact that 27 out of 30 SIRC procedures using the da Vinci Xi system were performed at Haeundae Paik Hospital, whereas all 50 procedures utilizing the da Vinci SP system were conducted at Ulsan University Hospital. The differences in these systems, combined with the operational dynamics at the two hospitals, which included a single dedicated assistant at Haeundae Paik Hospital and multiple rotating assistants at Ulsan University Hospital, may have influenced these results.

Regarding postoperative outcomes, there were no significant differences in surgical complications, such as the rate of gallbladder perforation during surgery, among the three groups. Consequently, compared to conventional methods, the employment of the newer da Vinci SP system not only ensures safety but also significantly improves the surgical convenience for surgeons.

During this study, the inclusion of a few cases of acute cholecystitis complicated comparisons. However, to broaden the indications for SIRC, including acute cholecystitis, it is crucial to ensure the availability of a diverse range of instruments for its unrestricted use. The da Vinci SP system is limited by its inability to use hemoclips, staplers, and suction, as well as by restrictions on the use of Hem-O-Lok® to only medium-large sized clips, which presents challenges for surgeons. To use larger Hem-O-Lok® clips, staplers, or hemoclips, the third robotic arm must be removed, or the assistant must insert laparoscopic instruments through a different hole in the trocar. However, achieving a favorable angle is difficult due to collisions with the robotic arm, making this process challenging. Although these limitations can be overcome by employing additional robotic instruments for tying and suturing, this leads to increased costs, thus offsetting the benefits of additional robotic instruments. When multiple instruments are necessary, such as for acute cholecystitis, SILC may be more advantageous than SIRC with the da Vinci SP system due to the unavailability of instruments.

Several studies, including meta-analyses, have suggested that SIRC results in less postoperative pain than SILC [4,7,11,12]. Lee and Lim [4] noted that postoperative pain is influenced by factors such as abdominal wall incisions, the extent of visceral surgery, and peritoneal irritation caused by pneumoperitoneum; however, no significant differences in these factors were observed between SILC and SIRC. Nevertheless, SIRC provides faster pain relief due to its reduced impact on surrounding organs. Kim et al. [7] found that immediate postoperative NRS scores were significantly lower with the da Vinci SP system compared to the da Vinci Xi system, attributing this to the ergonomic design of the wristed arm and the real-time instrument position display of the da Vinci SP system. We attribute the decreased postoperative pain associated with SIRC to minimal abdominal wall traction as the robotic arms enter and exit, facilitated by trocars fixed to the abdominal wall upon docking completion. In contrast, during SILC, significant traction of the abdominal wall toward the edges is often necessary to prevent collisions during instrument insertion and removal, frequently resulting in traction during the surgery. This discrepancy may account for the higher levels of pain perceived by patients undergoing SILC. However, the assessment of postoperative pain in this study was significantly influenced by variations in the number of patients opting for patient-controlled analgesia after all three surgical methods. After applying PSM, no significant differences were found in postoperative pain levels immediately after surgery, on the first postoperative day, or on the day of discharge among the three groups.

The da Vinci SP system necessitates a skin incision that is 0.5-cm longer than those required by the other two methods. While SILC and SIRC with the da Vinci Xi system require a 2.5-cm transumbilical incision for a 60-mm trocar, the da Vinci SP system necessitates a 3.0-cm incision for a 90-mm trocar due to the larger entry guide cannula size. Despite the aesthetic benefits of single-incision surgery, its higher incisional hernia rates, compared to conventional multiport surgery, represent a significant drawback [13-15]. A meta-analysis by Lyu et al. [14] revealed incisional hernia rates of 1.31% (29 of 2,208 patients) for SILC and 0.3% (7 of 2,304 patients) for conventional multiport laparoscopic cholecystectomy. Further research reported incisional hernia rates ranging from 0.3% to 5.4% for SILC and from 1.1% to 8.4% for multiport laparoscopic cholecystectomy [15]. The increased incidence of incisional hernias with SIRC is primarily due to two surgical risk factors: a wider umbilical incision and surgical site infections. Both factors significantly influence the hernia rate. Moreover, despite using various techniques for umbilical port closure, no technique was clearly superior [16,17]. In contrast, our study recorded no incisional hernias. Early in the adoption of SILC, the prevalence of hernias led to the implementation of fascia layer undermining dissection and interrupted suturing techniques, significantly reducing hernia rates. Additionally, while there were two cases of ileus and pneumonia in the SILC group, no wound- or hernia-related complications occurred. Moreover, no cases of wound infection or hernia were reported during our study's follow-up period.

Due to the retrospective nature of this study, the inability to collect objective data on surgeon stress load, such as real-time workload assessments or direct feedback, was a limitation. However, existing studies offer valuable insights into the surgeon workload, encompassing physical strain, mental effort, and time-related demands. Kim et al. [18] employed the NASA Task Load Index (NASA-TLX) to evaluate mental workload, revealing significantly higher scores for the SILC group compared to the SIRC and 3PLC (three-port laparoscopic cholecystectomy) groups (SIRC vs. SILC vs. 3PLC: 21.9 ± 11.1 vs. 44.3 ± 22.5 vs. 25.2 ± 11.6, $p < 0.001$). The NASA-TLX scale assesses mental workload across six subscales: mental, physical, and temporal demands, as well as effort, frustration, and perceived performance.

Additionally, the results of a randomized controlled trial [19] also indicated significantly lower stress levels for SIRC compared to those performing SILC, primarily due to the ergonomic advantages of robotic systems. These benefits include enhanced visualization, meticulous instrument control, and reduced physical strain in confined operational spaces. The da

Vinci SP system further amplifies convenience by incorporating three flexible arms, each with dual joints, which enhances precision while mitigating surgeon stress.

These findings underscore the ergonomic benefits and reduced workload of SP surgery, reinforcing its role in improving surgical convenience and effectiveness.

The higher cost of robotic surgery compared to conventional laparoscopic surgery presents a significant barrier in South Korea due to prevailing insurance reimbursement policies. Our study indicates that the costs associated with robotic approaches, including the da Vinci Xi and SP systems, are significantly higher than those for SILC, posing challenges for adoption within the current healthcare framework. However, given the need for additional surgical assistants in SILC and the dwindling surgical workforce, robotic surgery could become more cost-effective over time. By minimizing the need for multiple assistants, robotic systems have the potential to offset high initial expenses through enhanced efficiency and reduced labor costs.

Future studies should evaluate both direct and indirect costs of robotic surgery, including reduced surgeon workload, improved ergonomics, and lower staffing needs, potentially making robotic systems a more viable long-term option.

This study was strengthened by comparing outcomes of three different types of single-incision cholecystectomy performed by the same surgeon. However, the study also has limitations. First, its retrospective nature imposes inherent constraints. Second, although PSM was employed to counterbalance the patient numbers across surgical techniques, variations in the surgical systems used at two different institutions may have introduced bias. Third, the da Vinci Xi system was utilized during the early stage of robotic platform adoption, whereas the da Vinci SP system was employed in a later stage, a factor that should not be overlooked.

In conclusion, our study demonstrates that SIRC with the da Vinci SP system provides surgical outcomes comparable to conventional methods. Nevertheless, we recognize the limitation of lacking objective data on surgeon convenience or fatigue. Although the system is perceived to offer enhanced convenience, this is based on subjective evaluations and should be interpreted with caution. Further investigation with objective data is necessary to confirm the ergonomic and convenience benefits of the SP system.

FUNDING

None.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

ORCID

Jeong-Ik Park, https://orcid.org/0000-0002-1986-9246
Yong-Kyu Chung, https://orcid.org/0000-0002-2132-2450
Young Min Lee, https://orcid.org/0009-0009-9014-8562
Chang Woo Nam, https://orcid.org/0009-0007-2113-8366
Yang Won Nah, https://orcid.org/0000-0001-8161-9849

AUTHOR CONTRIBUTIONS

Conceptualization: JIP. Data curation: JIP, YKC, YML. Methodology: JIP, YKC, YML. Visualization: JIP, CWN, YWN. Writing - original draft: JIP. Writing - review & editing: all authors.

REFERENCES

1. Pietrabissa A, Sbrana F, Morelli L, Badessi F, Pugliese L, Vinci A, et al. Overcoming the challenges of single-incision cholecystectomy with robotic single-site technology. Arch Surg 2012;147:709-714.
2. Kroh M, El-Hayek K, Rosenblatt S, Chand B, Escobar P, Kaouk J, et al. First human surgery with a novel single-port robotic system: cholecystectomy using the da Vinci single-site platform. Surg Endosc 2011;25:3566-3573.
3. Wren SM, Curet MJ. Single-port robotic cholecystectomy: results from a first human use clinical study of the new da Vinci single-site surgical platform. Arch Surg 2011;146:1122-1127.
4. Lee SM, Lim JH. Comparison of outcomes of single incision robotic cholecystectomy and single incision laparoscopic cholecystectomy. Ann Hepatobiliary Pancreat Surg 2021;25:78-83.
5. Spinoglio G, Lenti LM, Maglione V, Lucido FS, Priora F, Bianchi PP, et al. Single-site robotic cholecystectomy (SSRC) versus single-incision laparoscopic cholecystectomy (SILC): comparison of learning curves. First European experience. Surg Endosc 2012;26:1648-1655.
6. Cruz CJ, Huynh F, Kang I, Lee WJ, Kang CM. Initial experiences of robotic SP cholecystectomy: a comparative analysis with robotic Si single-site cholecystectomy. Ann Surg Treat Res 2021;100:1-7.
7. Kim WJ, Choi SB, Kim WB. Feasibility and efficacy of single-port robotic cholecystectomy using the da Vinci SP® platform. JSLS 2022;26:e2021.00091.
8. Kang YH, Kang JS, Cho YS, Kim HS, Lee M, Han Y, et al. 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. Int J Med Robot 2022;18:e2345.
9. Choi YJ, Sang NT, Jo HS, Kim DS, Yu YD. A single-center experience of over 300 cases of single-incision robotic cholecystectomy comparing the da Vinci SP with the Si/Xi systems. Sci Rep 2023;13:9482.
10. Yokoe M, Hata J, Takada T, Strasberg SM, Asbun HJ, Wakabayashi G, et al. Tokyo Guidelines 2018: diagnostic criteria and severity grading of acute cholecystitis (with videos). J Hepatobiliary Pancreat Sci 2018;25:41-54.
11. Rudiman R, Hanafi RV, Almawijaya A. Single-site robotic chole-

cystectomy versus single-incision laparoscopic cholecystectomy: a systematic review and meta-analysis. Ann Gastroenterol Surg 2023;7:709-718.

12. Han DH, Choi SH, Kang CM, Lee WJ. Propensity score-matching analysis for single-site robotic cholecystectomy versus single-incision laparoscopic cholecystectomy: a retrospective cohort study. Int J Surg 2020;78:138-142.
13. Ricciardiello M, Grottola T, Panaccio P, Esposito LM, Montemitro C, Mucilli F, et al. Outcome after single-site robotic cholecystectomy: An initial single center's experience. Asian J Endosc Surg 2021;14:496-503.
14. Lyu Y, Cheng Y, Wang B, Zhao S, Chen L. Single-incision versus conventional multiport laparoscopic cholecystectomy: a current meta-analysis of randomized controlled trials. Surg Endosc 2020;34:4315-4329.
15. Balaphas A, Buchs NC, Naiken SP, Hagen ME, Zawodnik A, Jung MK, et al. Incisional hernia after robotic single-site cholecystectomy: a pilot study. Hernia 2017;21:697-703.
16. Migliore M, Arezzo A, Arolfo S, Passera R, Morino M. Safety of single-incision robotic cholecystectomy for benign gallbladder disease: a systematic review. Surg Endosc 2018;32:4716-4727.
17. Shaher Z. Port closure techniques. Surg Endosc 2007;21:1264-1274.
18. Kim HS, Han Y, Kang JS, Lee DH, Kim JR, Kwon W, et al. Comparison of single-incision robotic cholecystectomy, single-incision laparoscopic cholecystectomy and 3-port laparoscopic cholecystectomy - postoperative pain, cosmetic outcome and surgeon’s workload. J Minim Invasive Surg 2018;21:168-176.
19. Grochola LF, Soll C, Zehnder A, Wyss R, Herzog P, Breitenstein S. Robot-assisted versus laparoscopic single-incision cholecystectomy: results of a randomized controlled trial. Surg Endosc 2019;33:1482-1490.