Comparison of perioperative outcomes between hybrid uniportal robotic-assisted and uniportal video-assisted thoracoscopic surgery – A propensity score matching analysis

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ABSTRACT

BACKGROUND: To evaluate the perioperative outcomes of hybrid multi-arm robotic-assisted uniportal thoracoscopic surgery (H-URATS) using a laparoscopic stapling device, assess the safety and feasibility of the procedure, and summarize the surgical experience.

METHODS: The Department of Thoracic Surgery at Xinjiang Tumor Hospital has performed over 100 H-URATS procedures using endoscopic staplers and the robotic surgery platform. We collected the clinical data and perioperative outcomes from patients undergoing Uniportal Video-assisted Thoracoscopic Surgery (UVATS) and H-URATS between January 2023 and August 2024. Propensity score matching (PSM) was conducted based on clinical characteristics and perioperative outcomes were compared between the two groups after matching.

RESULTS: A total of 395 patients were included, with 109 in the H-URATS group and 286 in the UVATS group. After PSM, each group consisted of 92 patients. There were no significant differences between the H-URATS and UVATS groups in terms of chest drainage duration, postoperative hospital stay, conversion to thoracotomy rate, intensive care unit admission rate, postoperative complication rate, postoperative pathological types, or tumor TNM staging ($P > 0.05$). The H-URATS group had less intraoperative blood loss compared to the UVATS group ($P < 0.001$), and more lymph nodes (LNs) and LN stations were dissected in the H-URATS group ($P < 0.001$).

CONCLUSION: In terms of short-term results, our study confirms the safety and feasibility of H-URATS as a new minimally invasive technique. It combines the advantages of uniportal thoracoscopy and robotic surgery systems and demonstrates potential benefits in oncological outcomes and complex procedures such as segmentectomies.

KEYWORDS

Hybrid surgery, minimally invasive surgery, surgical staplers, uniportal robotic-assisted thoracoscopic surgery, uniportal video-assisted thoracoscopic surgery

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Background

Over the past two decades, minimally invasive surgery has gradually become the mainstream approach in thoracic surgery, benefiting an increasing number of

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patients. It is characterized by less postoperative pain, better cosmetic outcomes, shorter hospital stays, lower complication rates, and reduced perioperative mortality. Nowadays, for resectable non-small cell lung cancer (NSCLC), various major guidelines and expert consensus recommend minimally invasive surgery as the preferred surgical treatment.[1-5] Video-assisted thoracoscopic surgery (VATS) and robotic-assisted thoracoscopic surgery (RATS) are the two main approaches to minimally invasive surgery.

Since Gonzalez-Rivas *et al*.[6,7] performed the first uniportal VATS (UVATS) in 2011, its safety, feasibility, and efficacy have been confirmed by numerous clinical studies.[8-11] UVATS is now a mature technique. The da Vinci robotic surgical system, with its high-definition 3D view, tremor filtration, and wristed instruments with seven degrees of freedom, offers a better visual field controlled by the surgeon, and enhances precision, while providing a comfortable operating experience.[12,13] Consequently, RATS has gained increasing popularity among surgeons.

Recent retrospective studies and prospective randomized controlled trials (RCTs)[2,12,14,15] have confirmed the safety and feasibility of RATS in lung cancer treatment. However, compared to UVATS, multi-port RATS (MRATS), which requires 3–5 incisions, compromises the cosmetic effect and reduces the minimally invasive nature of the procedure, making it less acceptable to patients. To further minimize trauma from the surgical approach, Gonzalez,[16-21] the pioneer of UVATS, utilized the robotic surgery platform designed for multi-port surgery to first perform uniportal RATS (URATS), and defined pure URATS as robotic thoracic surgery performed through a single intercostal incision without rib retractors, utilizing a robotic camera, robotic dissection instruments, robotic thoracoscopic instruments, and robotic staplers.[22,23]

However, in developing countries, robotic-specific staplers are not widely available and are prohibitively expensive. In the absence of dedicated robotic staplers, some surgeons have attempted URATS using endoscopic staplers, successfully completing the procedure, which is then referred to as hybrid URATS (H-URATS).[24,25] Since January 2024, the Thoracic Surgery Department at Xinjiang Tumor Hospital has successfully performed over 100 cases of H-URATS. There is limited literature on the perioperative outcomes of H-URATS; therefore, we retrospectively collected cases of[26,27] H-URATS and UVATS performed at our center to explore the perioperative efficacy of H-URATS compared to UVATS.

Material and Methods

Study population

The Department of Thoracic Surgery at Xinjiang Tumor Hospital began performing robotic thoracic surgeries in May 2023, having already accumulated several years of experience and substantial clinical data with UVATS. This study includes patients who underwent UVATS or H-URATS at the Department of Thoracic Surgery of Xinjiang Tumor Hospital from January 2023 to August 2024. All surgeries were performed by the same surgical team. All patients had clear surgical indications and no severe comorbidities. The choice of surgical method was based on patient preference. Patients who underwent R0 resection and radical lymph node dissection (LN dissection), confirmed to have malignant tumors by pathology, were included. Informed consent was obtained from each patient before the study. Ultimately, a total of 395 patients were included in the study. The data collected included patient age, gender, lesion location, type of surgery, duration of surgery, intraoperative blood loss, total number of LNs dissected, number of LN stations dissected, postoperative hospital stay, chest drainage duration, perioperative complications, and total hospitalization costs. The total costs for the URATS group included the activation fee for the robotic surgery platform and the cost of the robotic arms. This study was approved by the ethics review board of our medical institution.

Surgical technique

All patients received general anesthesia with endotracheal intubation using a double-lumen tube and were placed in the lateral decubitus position at a 90° angle on the healthy side. The da Vinci Xi surgical robotic system was used, with two instrument arms and one camera arm. The main surgeon controlled Fenestrated bipolar forceps with the left hand and used Maryland bipolar forceps with the right hand [Figure 1]. For right-sided surgeries, the 2nd arm (camera), 3rd arm (left hand instrument), and 4th arm (right hand instrument) were used. For left-sided surgeries, the 1st arm (left hand instrument), 2nd arm (right hand instrument), and 3rd arm (camera) were used. The camera arm was placed posterior to the incision. Except for the camera arm, which used a trocar with a sealing interface to protect the camera, the other two arms did not use sealing interfaces to save space. The instruments were inserted through 8 mm trocars, and the three arms were aligned parallel to the incision, with the instruments crossing inside the pleural cavity. The laser crosshairs were aligned with the posterior side of the incision during positioning, parallel to the spine [Figure 2]. An endoscopic stapler was used to handle vessels, bronchi, and fissures, guided through the vascular and bronchial spaces with a No. 12 ventricular drainage tube to prevent collateral damage. The URATS incision was usually located between the anterior

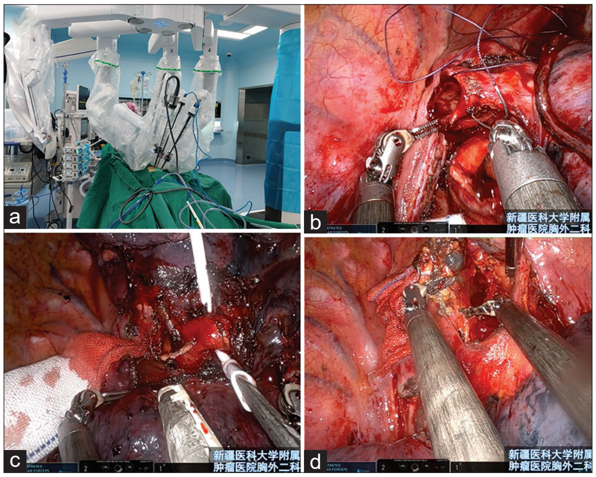

Figure 1: (a) Instrument arm selection (b) Suture the bronchus (c) Ventricular drain guided across the vessel (d) Lymph node clearance.

and mid-axillary lines at the 6th–7th intercostal space, approximately 3–4 cm long. For middle lobe resection of the right lung, the incision was placed more anteriorly, while for left lower lobe resection, it was placed slightly more posterior. Sleeve resection was performed through an incision at the 5th intercostal space between the anterior and mid-axillary lines.

Later in the study, the surgeon attempted to place the incision at the 5th intercostal space between the anterior and mid-axillary lines, which provided a similar angle of view to UVATS, matching the perspective most UVATS surgeons are accustomed to. This also facilitated the assistant's use of the endoscopic stapler for bronchial and vascular transection, as well as for hilum exposure. To improve visualization, the 30° camera could be swapped between robotic arms during surgery. When the assistant used the stapler, one of the robotic arms could be withdrawn to provide more space for the assistant's maneuvers. In UVATS, a single incision of about 4 cm was made between the anterior and mid-axillary lines at the 4th or 5th intercostal space. All surgical instruments were inserted through this single incision without rib spreading. During surgery, the assistant used a suction device and long oval forceps to aid in exposing the surgical field, retrieving specimens, and transecting the bronchi and vessels with an endoscopic stapler. All surgeries were performed by the same surgeon, who had extensive experience in UVATS. Before starting URATS, the surgical team had performed more than 100 MRATS procedures and was proficient with the da Vinci Xi operating system (surgical video available at: http://cgtvs.com/watch_video.php?v = 71U7DHYNOK56).

Statistical methods

To minimize the confounding bias and improve the comparability between the two groups, we conducted a 1:1 propensity score matching (PSM) analysis based

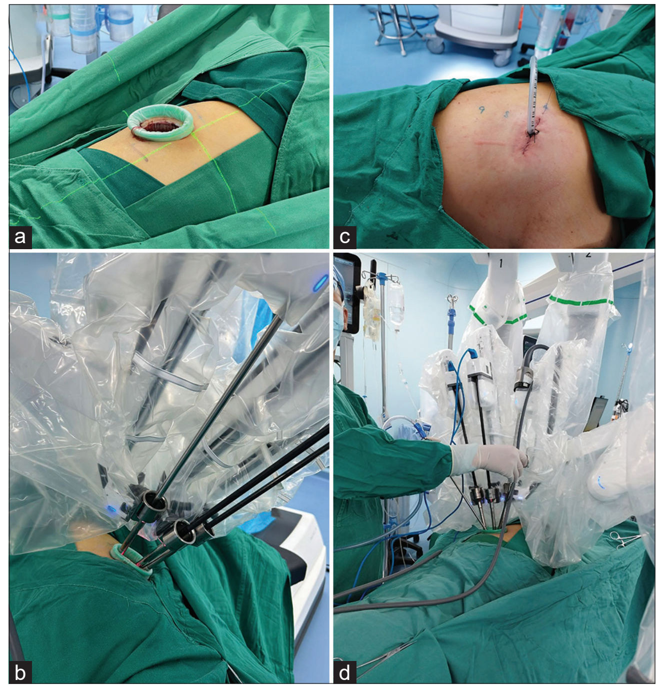

Figure 2: (a) Targeting (b) Instrument arm arrangement (c) Pictures of incision suture (d) Physician assistant assisted revealing.

on patient characteristics, including age, body mass index (BMI), actual/predicted forced expiratory volume in 1st s (FEV_1) (%), actual/predicted DLCO-SB (%), presence of cardiovascular risk factors, presence of pleural adhesions, lesion count, and surgical method. The nearest neighbor matching method was used with a caliper value of 0.02. After matching, a total of 184 patients were included in the study, with 92 in the H-URATS group and 92 in the UVATS group. After matching, there were no statistically significant differences between the groups in terms of the aforementioned variables, as shown in Table 1. Patients in the two groups were compared both before and after PSM. The continuous variables that conformed to or approximated a normal distribution were expressed as mean ± standard deviation ($\bar{x} \pm s$) and compared using an independent samples t-test. The continuous variables that did not follow a normal distribution were described as median and interquartile range (M [P25, P75]), and group comparisons were made using the Mann–Whitney U-test. The categorical variables were compared using the Chi-square test or Fisher's exact test. All statistical analyses were conducted using the SPSS software (version IBM SPSS Statistics 27, NewYork, USA). Statistical significance was defined as a $P < 0.05$.

Results

The clinical characteristics of the study population are shown in Table 1. A total of 395 patients were included in the study, with 109 undergoing H-URATS and

286 undergoing UVATS. Before PSM, the incidence of pleural adhesions discovered during surgery was higher in the UVATS group compared to the H-URATS group (41 [14.3%] vs. 5 [4.6%], $P = 0.007$). Regarding the type of surgical resection, segmentectomy was performed more frequently in the H-URATS group compared to the UVATS group (37 [34%] vs. 26 [9%], $P = 0.001$), while lobectomy was more commonly performed in the UVATS group compared to the H-URATS group (110 [39%] vs. 36 [33%], $P = 0.001$). Two patients in the UVATS group underwent sleeve lobectomy, whereas no sleeve lobectomy was performed in the H-URATS group. After PSM, there were 92 patients in each group who met the matching criteria. The groups were comparable in terms of age, BMI, actual/predicted FEV_1 (%), actual/predicted DLCO-SB (%), cardiovascular risk factors, pleural adhesions, lesion count, and resection type, particularly regarding resection type, where there was a high degree of similarity ($P = 1.00$).

The perioperative outcomes are presented in Table 2. All surgeries were successfully completed, and there were no perioperative deaths. After PSM, intraoperative blood loss was significantly lower in the H-URATS group compared to the UVATS group (30 [30, 50] vs. 120 [100, 150], $P < 0.001$). In addition, the number of LN stations and the total number of LNs dissected were significantly higher in the H-URATS group than in the UVATS group (LN stations: 8 [0, 9] vs. 2 [0, 7], $P < 0.001$; number of LNs dissected: 21 [0, 29] vs. 4.5 [0, 20], $P < 0.001$]. The operative time was shorter in the UVATS group than in the H-URATS group (130 [100, 157.5] vs. 172.5 [120, 245], $P < 0.001$), and the total hospital cost was lower in the UVATS group compared to

Table 1: Clinical characteristics of patients before and after propensity score matching

Characteristic	Before Matching			After Matching		
	U-VATS (*n*=286)	U-RATS (*n*=109)	*P*	U-VATS (*n*=92)	U-RATS (*n*=92)	*P*
Age	60.09±10.91	58.44±10.73	0.18	60.43±10.78	59.3±10.38	0.47
BMI	24.64±4.12	24.27±3.26	0.40	24.12±2.87	24.36±3.26	0.59
FEV1(%)	99.78±17.28	99.18±19.02	0.77	98.19±16.35	98.82±19.89	0.82
DLCO-SB (%)	96.99±24.53	97.63±20.48	0.79	95.15±26.84	98.37±18.61	0.35
Male	87 (30.4%)	43 (39.4%)	0.09	27 (29.3%)	38 (41.3%)	0.09
Female	199 (69.6%)	66 (60.6%)		65 (70.7%)	54 (58.7%)	
CVRF						
Present	96 (33.6%)	32 (29.4%)	0.42	30 (32.6%)	26 (28.3%)	0.63
Absent	190 (66.4%)	77 (70.6%)		62 (67.4%)	66 (71.7%)	
Pleural Adhesion						
Present	41 (14.3%)	5 (4.6%)	0.007	5 (5.4%)	4 (4.3%)	0.73
Absent	245 (85.7%)	104 (95.4%)		87 (94.6%)	88 (95.7%)	
Number of Lesions						
Single	242 (84.6%)	86 (78.9%)	0.18	71 (77.2%)	74 (80.4%)	0.72
Multiple	44 (15.4%)	23 (21.1%)		21 (22.8%)	18 (19.6%)	
Location of Lesion						
LUL	63 (22%)	17 (15.6%)	0.40	21 (22.8%)	14 (15.2%)	0.77
LLL	43 (15%)	17 (15.4%)		9 (9.8%)	15 (16.3%)	
RUL	93 (33%)	32 (29.4%)		25 (27.2%)	28 (30.4%)	
RUL + RLL	11 (4%)	8 (7.3%)		6 (6.5%)	7 (7.6%)	
RUL + RML	7 (2%)	2 (1.8%)		5 (5.4%)	2 (2.2%)	
RUL + RML + RLL	5 (2%)	1 (0.9%)		2 (2.2%)	1 (1.1%)	
RLL	39 (14%)	21 (19.3%)		17 (18.5%)	15 (16.3%)	
RML + RLL	3 (1%)	3 (2.8%)		0 (0%)	1 (1.1%)	
RML	16 (6%)	5 (4.6%)		4 (4.3%)	5 (5.4%)	
LUL + LLL	6 (2%)	3 (2.8%)		3 (3.3%)	3 (3.3%)	
Surgical Procedure						
Segmentectomy	26 (9%)	37 (34%)	0.001	24 (26.1%)	23 (25%)	1.00
Segmentectomy + WR	7 (2%)	9 (8%)		6 (6.5%)	6 (6.5%)	
Lobectomy	110 (39%)	36 (33%)		36 (39.1%)	36 (39.1%)	
Lobectomy + Segmentectomy	1 (0.3%)	0 (0%)		0 (0%)	0 (0%)	
Lobectomy + WR	9 (3%)	7 (6%)		7 (7.6%)	7 (7.6%)	
WR	131 (46%)	20 (18%)		19 (20.7%)	20 (21.7%)	
Sleeve Resection	2 (1%)	0 (0%)		0 (0%)	0 (0%)	

Discrete data are expressed as number with percentages: *n* (%), continuous data are expressed as mean±SD. CVRF: Cardiovascular Risk Factors. LUL: Left Upper Lobe, LLL: Left Lower Lobe, RUL: Right Upper Lobe, RML: Right Middle Lobe, RLL: Right Lower Lobe. CVRF, cardiovascular risk factors. WR: Wedge Resection. FEV1(%):FEV1 Actual/Predicted Value (%), DLCO-SB(%):DLCO-SBActual/Predicted Value (%).

Table 2: Postoperative characteristics of patients before and after propensity score matching

Variable	Before Matching		*P*	After Matching		*P*
	U-VATS (*n*=286)	U-RATS (*n*=109)		U-VATS (*n*=92)	U-RATS (*n*=92)	
Surgical Duration	120 (80, 160)	165 (116, 245)	<0.001	130 (100, 157.5)	172.5 (120, 245)	0.001
Intraoperative Blood Loss	100 (50, 150)	30 (30, 50)	<0.001	120 (100, 150)	30 (30, 50)	0.001
Days of Chest Tube Drainage	4 (3, 5)	4 (3, 5)	0.133	4 (3, 5)	4 (3, 5)	0.284
Total Drainage Volume	430 (270, 750)	550 (400, 830)	0.001	500 (300, 850)	622.5 (400, 915)	0.043
Postoperative Hospital Stay	4 (4, 5)	5 (4, 6)	0.099	4 (4, 5)	5 (4, 6)	0.14
NLNSD	1 (0, 7)	6 (0, 9)	<0.001	2 (0, 7)	8 (0, 9)	0.001
NLND	2 (0, 18)	15 (0, 27)	<0.001	4.5 (0, 20)	21 (0, 29)	0.013
Total Cost (in USD)	7380±118	9627±223	<0.001	7878±1965	9752±2421	<0.001
Conversion rate	1 (0.3%)	1 (0.9%)	0.476	0 (0%)	1 (1.1%)	1
Postoperative Complications						
Incomplete Intestinal Obstruction	0 (0%)	1 (0.9%)	0.005	0 (0%)	1 (1.1%)	0.061
Type I Respiratory Failure	1 (0.3%)	0 (0%)		0 (0%)	0 (0%)	
Air leak (>5 days)	2 (0.7%)	0 (0%)		1 (1.1%)	0 (0%)	
Atrial Fibrillation	8 (2.8%)	0 (0%)		2 (2.2%)	0 (0%)	
Pulmonary Infection	3 (1%)	0 (0%)		2 (2.2%)	0 (0%)	
PI, A, TI RF	0 (0%)	3 (2.8%)		0 (0%)	3 (3.3%)	
PI, TIRF	0 (0%)	1 (0.3%)		0 (0%)	1 (1.1%)	
Pulmonary Embolism	1 (0.3%)	1 (0.3%)		1 (1.1%)	0 (0%)	
Chylothorax	1 (0.3%)	0 (0%)		0 (0%)	0 (0%)	
RIJVT	0 (0%)	1 (0.3%)		0 (0%)	1 (1.1%)	
ICU Admission Rate	19 (6.6%)	8 (7.3%)	0.319	7 (7.6%)	6 (6.5%)	1
Postoperative Pathology						
Large Cell Carcinoma	2 (0.7%)	0 (0%)	0.678	1 (1.1%)	0 (0%)	0.966
Carcinoma In Situ	18 (6.3%)	8 (7.3%)		3 (3.3%)	6 (6.5%)	
Metastatic Tumor	13 (4.5%)	3 (2.8%)		3 (3.3%)	3 (3.3%)	
Adenosquamous Carcinoma	1 (0.3%)	1 (0.9%)		0 (0%)	1 (1.1%)	
AAH	0 (0%)	1 (0.9%)		0 (0%)	1 (1.1%)	
Carcinoid	1 (0.3%)	1 (0.9%)		1 (1.1%)	1 (1.1%)	
Benign	52 (18.2%)	14 (12.8%)		12 (13%)	12 (14%)	
Squamous Cell Carcinoma	17 (5.9%)	5 (4.6%)		7 (7.6%)	5 (5.4%)	
Sarcoma	1 (0.3%)	0 (0%)		0 (0%)	0 (0%)	
MIA	38 (13.3%)	18 (16.5%)		11 (12%)	12 (13%)	
Adenocarcinoma	142 (49.7%)	58 (53.2%)		53 (57.6%)	51 (55.4%)	
Adenocarcinoma + Metastasis	1 (0.3%)	0 (0%)		1 (1.1%)	0 (0%)	
TNM Staging						
Stage 0	18 (6.3%)	8 (7.3%)	0.078	3 (3.3%)	6 (6.5%)	0.452
Stage IV	15 (5.2%)	3 (2.8%)		3 (3.3%)	3 (3.3%)	
Benign	52 (18.2%)	14 (12.8%)		12 (13%)	12 (13%)	
AAH	0 (0%)	1 (0.9%)		0 (0%)	1 (1.1%)	
Stage IA1	59 (20.6%)	25 (22.9%)		24 (26.1%)	15 (16.3%)	
Stage IA2	73 (25.5%)	24 (22%)		23 (25%)	20 (21.7%)	
Stage IA3	15 (5.2%)	14 (12.8%)		6 (6.5%)	14 (15.2%)	
Stage IB	22 (7.7%)	5 (4.6%)		6 (6.5%)	5 (5.4%)	
Stage IIA	7 (2.4%)	6 (5.5%)		3 (3.3%)	6 (6.5%)	
Stage IIB	11 (3.8%)	2 (1.8%)		5 (5.4%)	2 (2.2%)	
Stage IIIA	13 (4.5%)	6 (5.5%)		7 (7.6%)	6 (6.5%)	
Stage IIIB	1 (0.3%)	1 (0.9%)		0 (0%)	1 (1.1%)	
N Staging						
N0	197 (68.9%)	83 (76.1%)	0.635	68 (73.9%)	68 (73.9%)	1.00
N1	8 (2.8%)	2 (1.8%)		3 (3.3%)	2 (2.2%)	
N2	14 (4.9%)	7 (6.4%)		6 (6.5%)	7 (7.6%)	

Discrete data are expressed as number with percentages: *n* (%), continuous data are expressed as mean±SD. NLNSD: Number of Lymph Node Stations Dissected, NLND: Number of Lymph Nodes Dissected. PI: Pulmonary Infection, A: Arrhythmia, T1RF: Type I Respiratory Failure. RIJVT: Right Internal Jugular Vein Thrombosis. AAH: Atypical Adenomatous Hyperplasia.MIA: Minimally Invasive Adenocarcinoma.

the H-URATS group (7390 ± 1965$ vs. 9624 ± 2420$, $P < 0.001$). Postoperative chest drainage volume was also less in the UVATS group than in the H-URATS group (500 [300, 850] vs. 622.5 [400, 915], $P < 0.001$). There were no significant differences between the H-URATS and UVATS groups in terms of chest drainage duration, postoperative hospital stay, conversion to thoracotomy, or ICU admission rate ($P > 0.05$). There were also no significant differences between the two groups in terms of postoperative pathological type, tumor TNM staging, or N staging ($P > 0.05$). The incidence of postoperative complications was not significantly different between the H-URATS and UVATS groups ($P = 0.061$), although the types of complications differed. Pulmonary infections and type I respiratory failure were more common in the H-URATS group, while atrial fibrillation was more common in the UVATS group. One patient in the UVATS group experienced pulmonary embolism postoperatively, and one patient in the H-URATS group developed a right internal jugular vein thrombosis confirmed by Doppler ultrasound. In both cases, D-dimer levels were markedly elevated, and subsequent vascular ultrasound and pulmonary artery CTA confirmed the diagnoses. Both patients were successfully treated with anticoagulation therapy and discharged without further complications.

Discussion

Compared with traditional open thoracotomy, VATS offers smaller incisions, less trauma, faster recovery, and shorter hospital stays while maintaining similar safety and oncological outcomes. Therefore, VATS is recommended as the first-choice surgical method for lung resections. In comparison to multi-port VATS, UVATS is more minimally invasive, cosmetically favorable, and results in higher patient satisfaction. Consequently, UVATS has become the most popular method of lung resection in Europe and Asia.[26,27] UVATS has been shown to have comparable oncological efficacy and safety to multi-port VATS and open thoracotomy.[28-31] Given this context, we used UVATS as the control group to evaluate the perioperative outcomes of URATS.

For resectable lung cancer, adequate and complete LN dissection is crucial for ensuring complete tumor resection, reducing recurrence rates, and prolonging survival, thereby ensuring the quality of minimally invasive surgery for NSCLC. In this study, we found that both before and after PSM, the H-URATS group had a higher number of LN stations dissected and a greater total number of LNs dissected compared to the UVATS group. These findings are consistent with previous studies on LN dissection during MRATS.[32-34] The superiority of H-URATS in LN dissection can be attributed to the da Vinci robotic system's high-definition 3D vision and wristed instruments with seven degrees of freedom, allowing for clearer visualization and more flexible manipulation. This enables the surgeon to better dissect the LNs around the blood vessels and bronchi. In this study, the main surgical instrument used by the robotic surgeon was the da Vinci Maryland bipolar forceps, a versatile tool with a sharp, curved beak design that allows for dissection, grasping, pulling, coagulating blood vessels, transecting, freeing blood vessels, placing vascular slings, simple suturing, and knot tying. Its comprehensive functionality and reliable performance significantly improved the efficiency and quantity of LN dissection, while reducing the number of robotic arms used, thereby lowering surgical costs.

We also found that intraoperative blood loss was significantly less in the H-URATS group compared to the UVATS group, which is mainly due to the robotic system's 10–15× magnified high-definition 3D view and its tremor-filtering robotic arms, which provide clearer exposure of the surgical field and allow for more precise and meticulous operations, facilitating the management of small blood vessel bleeding.

In terms of costs, the average total cost for the H-URATS group was ¥67,864 (approximately $9624), while the average total cost for the UVATS group was ¥52,028 (approximately $7390), meaning the H-URATS group had approximately ¥15,836 (about $2246, exchange rate: $1= ¥7.0497) higher costs than the UVATS group. Previous studies have reported that RATS costs approximately $3000–5000 more than VATS.[35-37] However, compared to the previously reported costs of RATS (multiport), the expenses associated with our cohort of H-RATS have decreased, which we attribute to efforts to minimize the number of robotic arms used during surgery. In China, the cost of utilizing the da Vinci robotic system includes both an activation fee and an instrument arm usage fee. The instrument arm usage fee is calculated based on the number of robotic arms deployed during each surgical procedure, with each arm being limited to a maximum of 10 uses. Most of the time, only three arms were used (camera arm, the main instrument in the surgeon's right hand being the Maryland bipolar forceps, which was seldom replaced, and the assistant instrument being the fenestrated bipolar forceps, avoiding the use of additional instruments like the electrocautery hook). This setup reduced the number of instrument changes, improved surgical efficiency, and lowered costs by minimizing the number of robotic arms used, as the unique design of the Maryland bipolar forceps effectively meets the requirements of our routine procedures.

In our study, there was no significant difference between the H-URATS and UVATS groups in terms of postoperative chest drainage duration. However, the total chest drainage volume was higher in the H-URATS group compared to the UVATS group. Few studies have analyzed the difference in chest drainage volume between URATS and UVATS during lung surgery. Based on our experience, URATS allows for the dissection of more LNs, which may lead to injury of adjacent bronchial arteries, veins, and lymphatic vessels, resulting in increased postoperative chest drainage volume. However, the similar chest drainage duration between the two groups suggests that H-URATS, while improving oncological outcomes, does not prolong postoperative drainage time.

We also observed that the operative time was significantly longer in the H-URATS group compared to the UVATS group. This may be related to the additional time required for docking and instrument setup in H-URATS. Furthermore, because it is a uniportal technique, more time may be spent withdrawing and adjusting the robotic arms as needed. Previous studies[37-39] on robotic-assisted segmentectomy have found that the robotic surgery platform's advantages, such as its high-definition 3D visualization, flexible wristed instruments, and integrated fluorescence system, help surgeons perform segmentectomies more effectively. The robotic system facilitates complex surgeries.[22,40,41] In our study, we also observed that the proportion of segmentectomy was higher in the H-URATS group before PSM.

After PSM, both groups of patients successfully completed the surgery. In the H-URATS group, one patient required conversion to thoracotomy due to massive bleeding caused by a frozen LN at the Hilar region, but no perioperative mortality was observed, and no adverse outcomes were attributed to severe complications.

Despite the high cost of the robotic system, including its maintenance and instrument expenses, which are significant factors limiting the widespread adoption of URATS, recent technological advancements and increased competition among manufacturers have resulted in a significant reduction in costs. In UVATS, at least three surgeons are typically required (one main surgeon, one assistant, and one camera holder). In contrast, URATS requires only two surgeons (one main surgeon and one bedside assistant),[37] which may lead to labor cost savings in high-volume medical centers. According to Nelson *et al*.,[42] although the initial purchase and maintenance costs of robotic systems are high, when adjusted for labor costs in high-volume centers, the overall cost difference between RATS, VATS, and open thoracotomy disappears. Furthermore, the ability to perform remote surgery is another advantage of RATS. Therefore, we believe that with the continuous development of robotic minimally invasive surgery and the decreasing costs of robotic surgical systems and their consumables, the application of URATS is bound to increase progressively.

Study limitations

Although we successfully implemented URATS using the robotic surgery platform and confirmed its feasibility and safety, the sample size of this study is relatively small. While some clinical data were collected, postoperative pain scores for the two groups were not obtained. In addition, this study was conducted in a single center, with clinical data collected from surgeries performed by a single surgeon, lacking long-term outcome data for the patients. The sample size in this study is relatively small, and it is a retrospective study. Although PSM was performed to minimize the selection bias, some unidentified confounding factors may still influence the results. To further compare the efficacy of URATS and UVATS, larger-scale, prospective, multicenter, and RCTs are needed.

Conclusion

In summary, hybrid uniportal URATS (H-URATS) using endoscopic staplers and a multi-arm robotic system is safe, feasible, and effective. Compared to UVATS, it results in less intraoperative blood loss and a higher number of dissected LNs and LN stations, yielding satisfactory perioperative outcomes. For surgeons with experience in UVATS and MRATS, the learning curve for H-URATS is short, making it suitable for broader clinical application.

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Authors' contributions

Jun Chen and Dongbo Luo conceptualized the study and contributed to its design. Together with Xiaogang Li, they conducted data analysis and interpretation. Jun Chen and Dongbo Luo were responsible for drafting the manuscript. All authors reviewed and approved the final version.

Ethical statement

This study was approved by the Institutional Review Board of Xinjiang Medical University Affiliated Tumor Hospital (Approval No. K-2024149). Written informed consentwasobtainedfromallparticipantspriortotheir inclusion in the study.This study was conducted in accordance with the principles of the Declaration of Helsinki(for human research).

Consent for publication

All authors have consented to the publication of this manuscript in its present form.

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Conflicts of interest

There are no conflicts of interest.

Data availability statement

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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