

Safety and Short-Term Clinical Outcomes of Robot-Assisted Lobectomy Based on the Tubeless Concept for Early-Stage Lung Cancer: A Retrospective Cohort Study

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AIM: The Tubeless comprehensive management model minimizes iatrogenic trauma by avoiding endotracheal intubation, chest tube placement, and urinary catheterization, while the robot-assisted thoracoscopic surgery system offers precise surgical manipulation and high-definition visualization. However, clinical evidence supporting the combination of these two approaches in early-stage lung cancer surgery remains limited. This study aimed to evaluate the short-term safety and clinical benefits of robot-assisted lobectomy based on the Tubeless concept in patients with early-stage lung cancer.

METHODS: A total of 120 patients with early-stage non-small cell lung cancer who underwent robot-assisted lobectomy in our department between January 2022 and May 2025 were retrospectively analyzed. According to the perioperative management approach, patients were divided into the Tubeless group ($n = 50$), which received spontaneous breathing anesthesia without indwelling chest tubes or urinary catheters, and the traditional group ($n = 70$), which received double-lumen endotracheal intubation with indwelling chest tubes and urinary catheters. Baseline characteristics, intraoperative parameters, postoperative pain scores, postoperative complications, length of hospital stay, patient satisfaction, and 30-day readmission rates were compared between the two groups.

RESULTS: No significant differences in baseline characteristics were observed between the two groups ($p > 0.05$). Similarly, no significant differences were observed in intraoperative blood loss, operative time, number of lymph node dissection stations, or total number of lymph nodes dissected ($p > 0.05$). Visual analogue scale (VAS) scores on postoperative days 1, 2, and 3 were significantly lower in the Tubeless group than in the traditional group ($p < 0.05$). The overall incidence of postoperative complications was significantly lower in the Tubeless group than in the traditional group ($p = 0.04$). Total hospital stay and postoperative hospital stay were significantly shorter in the Tubeless group than in the traditional group ($p < 0.001$). No significant difference was observed in the 30-day readmission rate between the two groups.

CONCLUSIONS: Robot-assisted lobectomy combined with the Tubeless comprehensive management approach is feasible and is associated with favorable short-term perioperative outcomes in patients with early-stage lung cancer. However, long-term oncologic outcomes, such as recurrence-free and overall survival, require further investigation.

Keywords: tubeless; lung cancer; robot-assisted lobectomy

Introduction

Lung cancer is one of the most prevalent malignant tumors, with high morbidity and mortality worldwide, and poses a serious threat to human health. According to global cancer statistics released by the International Agency for Research on Cancer, approximately 2.2 million new cases and 1.8 million deaths from lung cancer occur annually, accounting for 11.4% and 18.0% of all malignant tumors, respec-

tively, ranking first in cancer incidence and mortality [1]. For patients with resectable lung cancer, surgical treatment is currently the primary approach to achieve a radical cure and an important means of improving long-term survival. Therefore, surgery remains a core component of the comprehensive treatment of lung cancer [2,3,4].

With the rapid development of minimally invasive surgical techniques, video-assisted thoracoscopic surgery (VATS) has been widely adopted for the treatment of early-stage lung cancer, significantly reducing surgical trauma, relieving postoperative pain, shortening hospital stay, and accelerating postoperative recovery. Compared with traditional thoracotomy, VATS lobectomy offers the advantages of less trauma, faster recovery, and fewer complications while maintaining comparable oncological efficacy, and has become one of the standard surgical procedures for early-stage lung cancer [5,6,7]. However, VATS has limitations,

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including a two-dimensional field of view, limited flexibility of surgical instruments, and a relatively long learning curve. The advent of the robot-assisted thoracoscopic surgery (RATS) system has further advanced the development of minimally invasive thoracic surgery. The Da Vinci robotic surgical system provides three-dimensional high-definition visualization, tremor filtering, and flexible surgical instruments with seven degrees of freedom, enabling surgeons to perform precise anatomical procedures within the narrow thoracic cavity and overcome several limitations of conventional thoracoscopy [8,9]. Previous studies have demonstrated that robot-assisted lobectomy offers advantages in the completeness of lymph node dissection and the rate of conversion to thoracotomy, with a shorter learning curve than conventional VATS [10,11,12].

The Tubeless comprehensive management approach includes avoidance of tracheal intubation (maintenance of spontaneous breathing), no indwelling thoracic drainage tube, and no indwelling urinary catheter to minimize iatrogenic trauma and tube-related complications and to promote rapid postoperative recovery [13,14]. Tracheal intubation may cause airway mucosal injury, postoperative sore throat, and vocal cord dysfunction. Chest drainage tubes not only cause considerable pain but may also limit early patient mobilization, impair coughing and expectoration, and increase the risk of infection. Urinary catheterization increases the risk of urinary tract infection and may restrict postoperative patient mobilization [15,16]. Therefore, reducing or avoiding the use of these tubes may theoretically further reduce surgical stress and accelerate postoperative recovery.

The Tubeless approach in thoracic surgery originated in non-intubated thoracoscopic surgery. Pompeo et al. [17] first reported non-intubated thoracoscopic surgery for pulmonary nodules, confirming the safety and feasibility of this technique. Subsequently, non-intubated VATS lobectomy, segmentectomy, and other procedures have been investigated. A prospective randomized controlled study by Liu et al. [18] showed that non-intubated VATS lobectomy could shorten hospital stay and reduce the incidence of postoperative complications compared with conventional intubation anesthesia. On this basis, some researchers further explored the Tubeless comprehensive management model, which not only avoids endotracheal intubation but also eliminates the need for indwelling thoracic drainage tubes and urinary catheters. Chen et al. [19] reported their initial experience with Tubeless VATS pulmonary wedge resection, demonstrating that this management approach could further shorten hospital stay and improve patient satisfaction.

Patients with early-stage lung cancer increasingly have higher requirements for postoperative quality of life. How to minimize surgical trauma and accelerate the recovery process while ensuring radical tumor resection has become an important concern for thoracic surgeons. The combination of the Tubeless comprehensive management approach

and the robot-assisted surgical system remains at an exploratory stage. The robot-assisted surgical system provides precise surgical manipulation and clear visualization. Theoretically, combining these approaches may further enhance the benefits of minimally invasive thoracic surgery and achieve a truly minimally invasive approach. Based on this, this study retrospectively analyzed and compared the application effects of the Tubeless perioperative comprehensive management model and the conventional perioperative management model in patients undergoing robot-assisted lobectomy. Outcomes were comprehensively evaluated across multiple dimensions, including surgical safety, postoperative pain, postoperative complications, length of hospital stay, and patient satisfaction. The study aimed to investigate the safety and perioperative outcomes of the Tubeless perioperative comprehensive management model in robot-assisted lobectomy and provide an evidence-based foundation for clinical decision-making.

Methods

Subjects

This study was a retrospective cohort study. A total of 120 patients with early-stage non-small cell lung cancer who underwent robot-assisted lobectomy at Hunan Provincial People's Hospital between January 2022 and May 2025 were consecutively enrolled. Patients were divided into the Tubeless group ($n = 50$) and the traditional group ($n = 70$) based on the perioperative management model. The study was approved by the Ethics Committee of Hunan Provincial People's Hospital (2025-W-80) and conducted in accordance with the Declaration of Helsinki.

The inclusion criteria were as follows: age 18–75 years; preoperative imaging indicating suspected lung cancer; non-small cell lung cancer (NSCLC) confirmed by postoperative pathological examination; robot-assisted lobectomy and systematic lymph node dissection performed; American Society of Anesthesiologists (ASA) physical status grade I–II [20]; and absence of severe cardiopulmonary dysfunction or other surgical contraindications. The exclusion criteria were as follows: intraoperative conversion to thoracotomy; concomitant other malignant tumors; incomplete clinical data; and severe mental illness or cognitive impairment.

Regarding the group assignment, the attending surgeon decided to apply the Tubeless protocol based on patient selection criteria, including the absence of contraindications to spontaneous breathing anesthesia and no evidence of severe pleural adhesions or incomplete fissures on preoperative imaging, and on patient preference following shared decision-making. Patients who did not meet the Tubeless criteria or declined the Tubeless approach received conventional management. Therefore, this non-randomized group assignment based on surgeon selection criteria and patient preference may introduce potential selection bias. Factors such as pleural adhesions and incomplete fissures may in-

fluence both group assignment and postoperative outcomes; therefore, this limitation should be considered when interpreting the results.

Surgical Management

Tubeless group: The Tubeless group received spontaneous breathing anesthesia. No muscle relaxants were administered before surgery; intravenous sedation and analgesia combined with local anesthesia were used, spontaneous breathing was maintained during surgery, and no double-lumen endotracheal tube was inserted. Artificial pneumothorax was established during surgery. Vital signs, end-tidal carbon dioxide partial pressure, and blood gas analysis were monitored during surgery, and the depth of anesthesia was adjusted as necessary. No thoracic drainage tube or urinary catheter was placed after surgery.

In the Tubeless group, an air leakage test was routinely performed before chest closure. The anesthesiologist manually inflated the lungs via the anesthesia circuit to a pressure of 25–30 cmH₂O for 5–10 seconds, while the surgical field was submerged in warmed saline. A negative test (no significant air leakage) was defined as the absence of visible bubbles during a 10-second observation period. The presence of 1–2 isolated small bubbles without continuous recurrence was also considered acceptable. After confirming the absence of significant air leakage, the wound and mediastinal pleura were inspected for active bleeding. Thoracic drainage was withheld only when the air leakage test was negative, and no active bleeding was identified.

Bedside chest radiography was performed in the post-anesthesia care unit (PACU) and at 6 and 24 h after surgery to monitor for pneumothorax or pleural effusion. Indications for chest tube reinsertion included: (1) symptomatic pneumothorax (e.g., dyspnea, hypoxia, or hemodynamic instability), regardless of size; (2) asymptomatic pneumothorax occupying $\geq 30\%$ of the hemithorax on chest radiography; or (3) moderate-to-large pleural effusion causing respiratory symptoms or hemodynamic compromise. Small, asymptomatic pneumothorax ($<30\%$) or trace-to-small pleural effusion without symptoms was managed conservatively with observation.

Traditional group: surgery was performed by the same experienced robotic surgical team using the Da Vinci surgical system. Artificial pneumothorax was established during surgery, followed by lobectomy and systematic lymph node dissection. Patients in the traditional group received general anesthesia with conventional double-lumen endotracheal intubation, and postoperative thoracic drainage tubes and urinary catheters were placed. The surgical procedure, extent of resection, and lymph node dissection were the same as those in the Tubeless group and were performed by the same surgical team.

Observation Indicators

Baseline data were collected, including age, sex, body mass index (BMI), smoking history, comorbidities (hypertension, diabetes mellitus, and chronic obstructive pulmonary disease (COPD)), lesion location, Tumor-Node-Metastasis (TNM) stage [21], and pathological type. Intraoperative blood loss, operative time, number of lymph node dissection stations, and total number of lymph nodes dissected were recorded. A visual analogue scale (VAS) [22] was used to assess pain severity on days 1, 2, and 3 after surgery. Postoperative complications, including pleural effusion, pneumonia, subcutaneous emphysema, atelectasis, and poor wound healing, occurring within 30 days after surgery, were recorded. The rate of thoracentesis or chest tube reinsertion, total length of hospital stay, and postoperative hospital stay were recorded. The 30-day readmission rate was also recorded. A 5-point Likert scale (very satisfied, satisfied, neutral, dissatisfied, very dissatisfied) was used in a patient satisfaction survey administered before discharge.

Statistical Analysis

SPSS version 26.0 (IBM Corp., Armonk, NY, USA) statistical software was used for data analysis. The normality of continuous variables was assessed using the Shapiro-Wilk test. Measurement data conforming to a normal distribution ($p > 0.05$) were expressed as mean $\pm$ standard deviation, and between-group comparisons were performed using the independent-samples *t*-test. Data not conforming to a normal distribution ($p < 0.05$) were expressed as median (interquartile range), and the Mann-Whitney *U* test was used for between-group comparisons. For VAS scores at the three postoperative time points, a two-way repeated-measures ANOVA was performed to assess the effects of group, time, and their interaction. Mauchly's test was used to assess sphericity, with the Greenhouse-Geisser correction applied when the assumption was violated. Post hoc comparisons were performed using the Bonferroni correction. Count data were expressed as frequencies and percentages (%), and the chi-square (χ^2) test or Fisher's exact test was used for between-group comparisons. In addition to *p*-values, the standardized mean difference was calculated for each baseline covariate to assess the balance between the two groups. An SMD <0.2 was considered indicative of good balance. A *p*-value < 0.05 was considered statistically significant.

Results

Comparison of Baseline Data Between the Two Groups

A total of 120 patients with early-stage lung cancer were enrolled, including 50 patients in the Tubeless group and 70 patients in the traditional group. Comparison of baseline data showed no significant differences in age, BMI, sex, hypertension, diabetes mellitus, smoking history, COPD his-

Table 1. Comparison of baseline characteristics between the two groups.

Variables	Total (n = 120)	Tubeless group (n = 50)	Traditional group (n = 70)	Test statistic	p-value	SMD
Age, years, mean $\pm$ SD	60.29 $\pm$ 5.32	60.14 $\pm$ 5.76	60.40 $\pm$ 5.03	$t = -0.26$	0.79	0.05
BMI, kg/m ² , mean $\pm$ SD	23.87 $\pm$ 1.08	23.92 $\pm$ 1.00	23.84 $\pm$ 1.14	$t = 0.40$	0.69	-0.07
Sex, n (%)				$\chi^2 = 0.43$	0.51	
Male	69 (57.50)	27 (54.00)	42 (60.00)			0.12
Female	51 (42.50)	23 (46.00)	28 (40.00)			-0.12
Hypertension, n (%)				$\chi^2 = 0.13$	0.72	
No	99 (82.50)	42 (84.00)	57 (81.43)			-0.07
Yes	21 (17.50)	8 (16.00)	13 (18.57)			0.07
Diabetes mellitus, n (%)				-	0.70	
No	113 (94.17)	48 (96.00)	65 (92.86)			-0.12
Yes	7 (5.83)	2 (4.00)	5 (7.14)			0.12
Smoking history, n (%)				$\chi^2 = 0.27$	0.60	
No	94 (78.33)	38 (76.00)	56 (80.00)			0.10
Yes	26 (21.67)	12 (24.00)	14 (20.00)			-0.10
COPD, n (%)				-	0.70	
No	113 (94.17)	48 (96.00)	65 (92.86)			-0.12
Yes	7 (5.83)	2 (4.00)	5 (7.14)			0.12
Lesion location, n (%)				$\chi^2 = 0.19$	1.00	
Left upper lobe	20 (16.67)	9 (18.00)	11 (15.71)			-0.06
Left lower lobe	20 (16.67)	8 (16.00)	12 (17.14)			0.03
Right upper lobe	40 (33.33)	17 (34.00)	23 (32.86)			-0.02
Right middle lobe	12 (10.00)	5 (10.00)	7 (10.00)			0.00
Right lower lobe	28 (23.33)	11 (22.00)	17 (24.29)			0.05
TNM stage, n (%)				$\chi^2 = 0.24$	0.97	
IA1	25 (20.83)	11 (22.00)	14 (20.00)			-0.05
IA2	38 (31.67)	16 (32.00)	22 (31.43)			-0.01
IA3	29 (24.17)	11 (22.00)	18 (25.71)			0.09
IB	28 (23.33)	12 (24.00)	16 (22.86)			-0.03
Pathological type, n (%)				-	0.68	
Invasive adenocarcinoma	110 (91.67)	46 (92.00)	64 (91.43)			-0.02
Squamous cell carcinoma	6 (5.00)	3 (6.00)	3 (4.29)			-0.09
Microinvasive adenocarcinoma	4 (3.33)	1 (2.00)	3 (4.29)			0.11

Note: BMI, body mass index; COPD, chronic obstructive pulmonary disease; TNM, Tumor-Node-Metastasis. - indicates that Fisher's exact test was used for statistical analysis.

tory, lesion location, TNM stage, or pathological type between the two groups ($p > 0.05$). The SMDs for all baseline variables were less than 0.2, indicating good baseline comparability between the two groups (Table 1).

Comparison of Surgical Outcomes

The comparison of surgical conditions showed no significant differences in intraoperative blood loss, operative time, number of lymph node dissection stations, or total number of lymph nodes dissected between the Tubeless group and the traditional group ($p > 0.05$), indicating that the Tubeless comprehensive management approach did not adversely affect the completeness or safety of the surgical procedure (Table 2).

Comparison of Postoperative Pain and Complications

Repeated-measures ANOVA revealed significant main effects of group ($F = 19.27, p < 0.01$) and time ($F = 1198.83, p < 0.01$), with no significant group-by-time interaction ($F = 2.51, p = 0.08$). Post hoc comparisons with Bonferroni correction confirmed that VAS scores were significantly lower in the Tubeless group at 1, 2, and 3 days after surgery (all $p < 0.05$) (Table 3). In terms of complications, the overall incidence in the Tubeless group was 14.0% (7/50), significantly lower than in the traditional group (30.0% [21/70]) ($p = 0.04$). No significant differences were observed in the incidence of individual complications, including pleural effusion, pneumonia, subcutaneous emphysema, atelectasis, and poor wound healing, between the two groups ($p > 0.05$) (Table 3, Fig. 1).

Table 2. Comparison of surgical outcomes between the two groups.

Variables	Total (n = 120)	Tubeless group (n = 50)	Traditional group (n = 70)	Test statistic	p-value
Intraoperative blood loss, mL, mean $\pm$ SD	17.54 $\pm$ 3.16	17.14 $\pm$ 3.40	17.83 $\pm$ 2.98	$t = -1.18$	0.24
Operative time, min, mean $\pm$ SD	203.30 $\pm$ 6.84	204.20 $\pm$ 6.99	202.66 $\pm$ 6.70	$t = 1.22$	0.23
Number of lymph node stations dissected, median (Q ₁ , Q ₃)	6.00 (5.00, 6.00)	6.00 (5.00, 6.00)	6.00 (5.00, 6.00)	$Z = 0.10$	0.92
Total number of lymph nodes dissected, median (Q ₁ , Q ₃)	16.00 (15.00, 16.00)	16.00 (15.00, 16.00)	16.00 (15.00, 16.00)	$Z = 0.29$	0.78

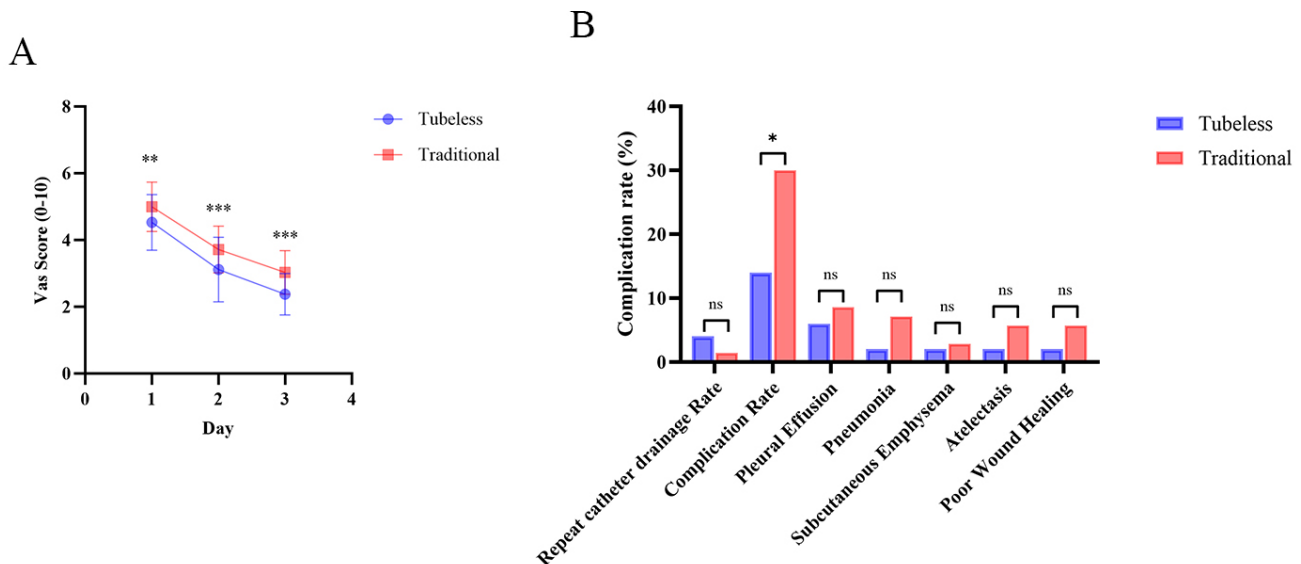


Fig. 1. Comparison of postoperative pain and complications between the two groups. (A) Visual analogue scale (VAS) scores at postoperative days 1, 2, and 3. (B) Overall postoperative complication rate and individual complications in the two groups. Note: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns, not significant.

Comparison of Length of Hospital Stay and Patient Satisfaction

Comparison of hospitalization duration showed that total hospital stay and postoperative hospital stay were significantly shorter in the Tubeless group than in the traditional group ($p < 0.001$). No significant difference was observed in the 30-day readmission rate between the two groups ($p > 0.05$).

In terms of patient satisfaction, the overall satisfaction rate in the Tubeless group was significantly higher than that in the traditional group. The proportion of patients reporting being very satisfied was 86.00% (43/50), significantly higher than in the traditional group [68.57% (48/70)] ($p = 0.03$). No dissatisfied or very dissatisfied cases were reported in either group (Table 4, Fig. 2).

Discussion

The retrospective analysis of 120 patients with early-stage non-small cell lung cancer who underwent robot-assisted lobectomy demonstrated that the comprehensive management model based on the Tubeless concept is safe and feasible in clinical practice. The results of this study showed

that the Tubeless group achieved better short-term clinical outcomes than the traditional group in postoperative pain control, complication rates, length of hospital stay, and patient satisfaction, without adversely affecting the completeness of surgical procedures or perioperative safety.

The core of the Tubeless comprehensive management approach is to minimize iatrogenic stimulation and catheter-related complications by avoiding tracheal intubation, thoracic drainage tubes, and urinary catheters. The results of this study showed that VAS scores on days 1, 2, and 3 after surgery were significantly lower in the Tubeless group than in the traditional group. These findings are consistent with those of previous studies. Li et al. [23] conducted a prospective randomized controlled study comparing different Tubeless anesthesia strategies in VATS wedge resection and observed that VAS scores in patients receiving a laryngeal mask airway combined with paravertebral nerve block were significantly lower than those in the double-lumen endotracheal intubation group at rest and during coughing within 6–24 hours after surgery. The improvement in postoperative pain observed in this study may be attributed to multiple factors, including the preservation

Table 3. Comparison of postoperative pain and complications between the two groups.

Variables	Total (n = 120)	Tubeless group (n = 50)	Traditional group (n = 70)	Test statistic	p-value
VAS score on postoperative day 1, mean $\pm$ SD	4.80 $\pm$ 0.81	4.53 $\pm$ 0.83	5.00 $\pm$ 0.74	$t = -3.22$	<0.01
VAS score on postoperative day 2, mean $\pm$ SD	3.47 $\pm$ 0.87	3.12 $\pm$ 0.97	3.72 $\pm$ 0.70	$t = -3.76$	<0.001
VAS score on postoperative day 3, mean $\pm$ SD	2.75 $\pm$ 0.72	2.37 $\pm$ 0.64	3.03 $\pm$ 0.66	$t = -5.44$	<0.001
Thoracentesis or chest tube reinsertion rate, n (%)				-	0.57
No	117 (97.50)	48 (96.00)	69 (98.57)		
Yes	3 (2.50)	2 (4.00)	1 (1.43)		
Postoperative complications, n (%)				$\chi^2 = 4.17$	0.04
No	92 (76.67)	43 (86.00)	49 (70.00)		
Yes	28 (23.33)	7 (14.00)	21 (30.00)		
Pleural effusion, n (%)				$\chi^2 = 0.03$	0.86
No	111 (92.50)	47 (94.00)	64 (91.43)		
Yes	9 (7.50)	3 (6.00)	6 (8.57)		
Pneumonia, n (%)				-	0.40
No	114 (95.00)	49 (98.00)	65 (92.86)		
Yes	6 (5.00)	1 (2.00)	5 (7.14)		
Subcutaneous emphysema, n (%)				-	1.00
No	117 (97.50)	49 (98.00)	68 (97.14)		
Yes	3 (2.50)	1 (2.00)	2 (2.86)		
Atelectasis, n (%)				-	0.40
No	115 (95.83)	49 (98.00)	66 (94.29)		
Yes	5 (4.17)	1 (2.00)	4 (5.71)		
Poor wound healing, n (%)				-	0.40
No	115 (95.83)	49 (98.00)	66 (94.29)		
Yes	5 (4.17)	1 (2.00)	4 (5.71)		

Note: VAS, visual analogue scale. VAS scores were assessed on postoperative days 1, 2, and 3. Postoperative complications were recorded within 30 days after surgery. - indicates that Fisher's exact test was used for statistical analysis.

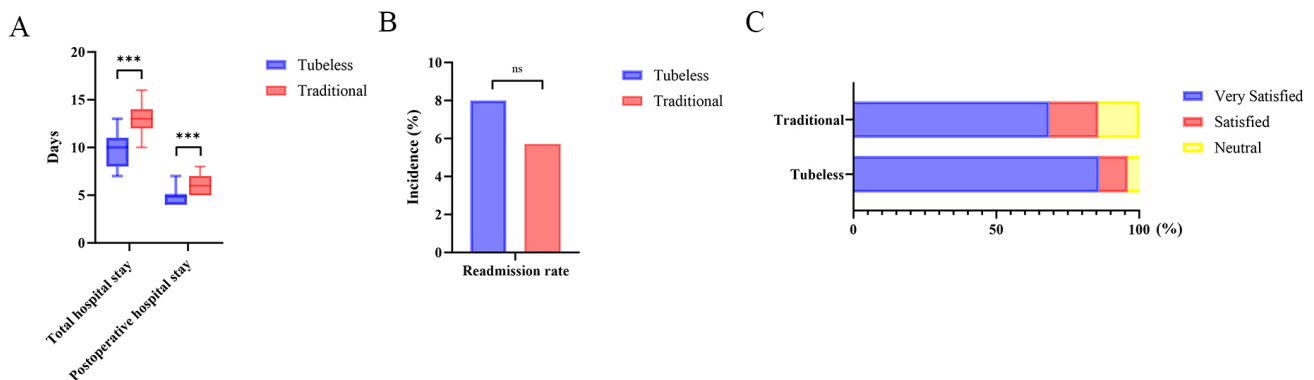


Fig. 2. Comparison of hospital stay, readmission, and patient satisfaction between the two groups. (A) Total hospital stay and postoperative hospital stay. (B) 30-day readmission rates after surgery. (C) Patient satisfaction levels (very satisfied, satisfied, and neutral). Note: *** $p < 0.001$; ns, not significant.

of spontaneous breathing anesthesia, avoidance of tracheal intubation-related injury, elimination of drainage tube stimulation, and preservation of normal respiratory physiology. A previous study has confirmed that the thoracic drainage tube is an important factor influencing postoperative pain [24]. Therefore, the Tubeless comprehensive management approach may provide better postoperative analgesia by avoiding injury from tracheal intubation, eliminating stim-

ulation from the drainage tube, and preserving normal respiratory physiology.

In terms of postoperative complications, the overall incidence of complications in the Tubeless group was significantly lower than in the traditional group. Notably, the incidence of respiratory complications, including pneumonia and atelectasis, was numerically lower in the Tubeless group than in the traditional group in this study. Cui et al.

Table 4. Comparison of hospital stay, readmission, and patient satisfaction between the two groups.

Variables	Total (n = 120)	Tubeless group (n = 50)	Traditional group (n = 70)	Test statistic	p-value
Total hospital stay, days, median (Q ₁ , Q ₃)	12.00 (10.00, 13.00)	10.00 (8.00, 11.00)	13.00 (12.00, 14.00)	Z = 7.30	<0.001
Postoperative hospital stay, days, median (Q ₁ , Q ₃)	5.00 (5.00, 7.00)	5.00 (4.00, 5.00)	6.00 (5.00, 7.00)	Z = 6.01	<0.001
30-day readmission, n (%)	8 (6.67)	4 (8.00)	4 (5.71)	-	0.72
Overall satisfaction, n (%)	108 (90.00)	48 (96.00)	60 (85.71)	$\chi^2 = 3.43$	0.06
Very satisfied, n (%)	91 (75.83)	43 (86.00)	48 (68.57)	$\chi^2 = 4.83$	0.03
Satisfied, n (%)	17 (14.17)	5 (10.00)	12 (17.14)	$\chi^2 = 1.22$	0.27
Neutral, n (%)	12 (10.00)	2 (4.00)	10 (14.29)	$\chi^2 = 3.43$	0.06
Dissatisfied, n (%)	0 (0)	0 (0)	0 (0)		
Very dissatisfied, n (%)	0 (0)	0 (0)	0 (0)		

Note: Overall satisfaction was defined as the proportion of patients reporting “very satisfied” or “satisfied”. Patient satisfaction was assessed using a 5-point Likert scale: very satisfied, satisfied, neutral, dissatisfied, and very dissatisfied. No patients selected “dissatisfied” or “very dissatisfied”. - indicates that Fisher’s exact test was used for statistical analysis.

[13] also observed a similar phenomenon, which may be attributed to the Tubeless strategy, which avoids tracheal intubation-related airway mucosal damage and preserves physiological airway clearance. In addition, the absence of an indwelling chest tube allows early ambulation, promotes deep breathing and effective coughing, and may further potentially contribute to the prevention of atelectasis and pneumonia.

In terms of surgical safety, no significant differences were observed between the two groups in intraoperative blood loss, operative time, number of lymph node dissection stations, or total number of lymph nodes dissected, indicating that the Tubeless comprehensive management approach did not compromise the accuracy or thoroughness of the surgical procedure. In this study, the median number of lymph nodes dissected in the Tubeless group was 16, meeting the requirements for systematic lymph node dissection. Robot-assisted lobectomy has demonstrated advantages in achieving radical lymph node dissection [25,26,27]. The high-definition, three-dimensional visualization and flexible operating instruments of the robotic surgical system provide an ideal platform for implementing the Tubeless comprehensive management mode. Even without endotracheal intubation, a clear surgical field and precise anatomical identification can be maintained, thereby further ensuring the quality of the surgical procedure.

In terms of hospitalization time, both total hospital stay and postoperative hospital stay were significantly shorter in the Tubeless group than in the traditional group, reflecting the advantages of the Tubeless comprehensive management model in accelerating postoperative recovery [28]. Meanwhile, no significant difference was observed in the 30-day readmission rate between the two groups, suggesting that the shorter hospital stay in the Tubeless group was not achieved at the expense of an increased risk of readmission. These findings provide preliminary support for the safety of enhanced postoperative recovery within the Tube-

less management strategy. Chen et al. [29] reported a mean postoperative hospital stay of 5.9 days after non-intubated thoracoscopic lobectomy, which was longer than that observed in the present study (median, 5.0 days in the Tubeless group). This difference may be attributed to the routine use of chest tubes in their study and advances in perioperative management over the past decade. The patient satisfaction survey showed that the proportion of patients reporting being very satisfied in the Tubeless group was 86.00%, significantly higher than the 68.57% observed in the traditional group. Similar patient-reported benefits have also been observed in other Tubeless applications [30]. In this study, the higher satisfaction rate may be associated with rapid recovery, pain relief, and early return to normal daily activities. However, because satisfaction was assessed before discharge, the length of hospital stay itself may have influenced satisfaction independently of clinical outcomes. For example, patients with longer hospital stays may report lower satisfaction because of non-clinical factors such as inconvenience or discomfort. Therefore, this potential confounding factor should be considered when interpreting the satisfaction findings.

Compared with previous studies, the innovation of this study is combining the Tubeless concept with a robot-assisted surgical system. Previous studies on Tubeless have primarily focused on VATS. With its precise operation and clear visualization, the robotic system can theoretically further reduce surgical traumatic stress and provide a favorable platform for implementing the Tubeless comprehensive management model. This study provides preliminary evidence supporting the safety and potential advantages of the robot-assisted + Tubeless approach and provides a new perspective for the development of minimally invasive thoracic surgery.

This study still has some limitations. First, this was a single-center retrospective study. Although there were no significant differences in baseline data between the two groups

and the SMD for all baseline variables was <0.2 , indicating good balance, unmeasured confounding factors (such as the degree of lung fissure development and pleural adhesions) may still have influenced group selection, leading to selection bias. In addition, the lack of a predefined assignment protocol may have introduced selection bias, although the assignment criteria were clarified in the Methods section. Future prospective studies are warranted to validate our findings. Second, the short duration of postoperative follow-up did not allow assessment of long-term oncologic outcomes. In the future, multicenter, large-sample, prospective randomized controlled trials are needed to further verify the long-term efficacy and clinical value of the Tubeless strategy in robot-assisted lobectomy. In addition, the Tubeless group differed from the traditional group in anesthesia mode, thoracic drainage tube management, and urinary catheter management. Therefore, the observed clinical advantages resulted from multiple factors and could not be attributed to a single intervention. Subsequent studies could adopt a factorial design to further clarify the specific contributions of each component.

Conclusions

In summary, robot-assisted lobectomy with the Tubeless comprehensive management model is safe and feasible for the treatment of early-stage lung cancer. Patients had lower postoperative pain scores, a lower incidence of complications, shorter hospital stays, and higher satisfaction. However, given the short follow-up period, long-term oncologic outcomes, such as recurrence-free survival and overall survival, remain to be evaluated in future studies. This approach represents a promising minimally invasive strategy with the potential to enhance postoperative recovery.

Availability of Data and Materials

The data analyzed are available from the corresponding author upon reasonable request.

Author Contributions

ZLJ, JHY and ZXD designed the research study. ZLJ, JHY and JTC performed the research. ZXD analyzed the data. ZLJ and ZXD drafted the article. All authors have been involved in revising the manuscript critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

This study obtained approval from the Ethics Committee of Hunan Provincial People's Hospital (2025-W-80). All patients were informed of all possible clinical outcomes of the

different treatments and signed a written informed consent. The study was conducted in accordance with the Declaration of Helsinki.

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Conflict of Interest

The authors declare no conflict of interest.

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