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Original Article

Impact of drainage strategies on recovery in Stage III tuberculous empyema: a retrospective study

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Abstract
Introduction: Tuberculous empyema, a severe complication of pulmonary tuberculosis, often requires surgical intervention in stage III to remove fibrotic tissue and restore lung function.
Methodology: This retrospective study enrolled 224 stage III tuberculous empyema patients undergoing single-port thoracoscopic decortication and closed chest drainage. Patients were divided into three groups: Single-Tube group (n = 42), Double-Tube group (n = 51), and Double-Tube with Negative Pressure (Double-NP) group (n = 131, with -8 to -10 cm H_2O negative pressure applied from postoperative day 2). Primary outcomes included postoperative drainage volume, chest tube duration, hospital stay, complications, and Visual Analog Scale (VAS) pain scores. Data were analyzed using Analysis of Variance (ANOVA), chi-square tests, and multivariate regression.
Results: Baseline characteristics were comparable across groups. Postoperative drainage volumes were similar, but chest tube duration and hospital stay were significantly shorter in the Double-Tube and Double-NP groups compared to the Single-Tube group ($p < 0.05$). The Double-NP group exhibited lower rates of persistent air leak, pleural effusion, atelectasis, and reintubation ($p < 0.05$). VAS scores were significantly lower in the Single-Tube group than in the Double-Tube and Double-NP groups ($p < 0.01$).
Conclusions: While the double-tube with delayed low-negative-pressure drainage strategy did not reduce postoperative pain, it significantly shortened chest tube duration and hospital stay while reducing complications, thereby improving overall prognosis in stage III tuberculous empyema patients.

Key words: Tuberculous empyema; Single-port video-assisted thoracoscopic decortication; Chest drainage strategy; Negative pressure drainage.

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Introduction

Tuberculous empyema is a grave complication of pulmonary tuberculosis characterized by the accumulation of pus and fibrous tissue in the pleural cavity, severely impairing lung function. The condition progresses through three stages: exudative (stage I), fibrinopurulent (stage II), and organized (stage III) [1]. While conservative treatments like chest drainage suffice for stages I and II, stage III often necessitates surgical intervention due to lung compression, extensive pleural adhesions, and thoracic deformities [2]. Single-port thoracoscopic decortication has emerged as a preferred approach for stage III patients, offering minimal invasiveness, faster recovery, and shorter hospital stays [1,3,4]. However, this procedure carries risks of alveolar injury, and increasing postoperative complications such as air leaks, infections, pneumothorax, pleural effusion, and atelectasis, which can delay recovery and escalate healthcare costs.

Postoperative chest drainage is pivotal in evacuating fluid and air, reducing complication risks, and promoting lung re-expansion. Yet, no standardized protocol exists [5,6]. Some studies advocate double-tube drainage for its broader coverage compared to single-tube drainage, while others highlight the role of negative pressure in enhancing lung re-expansion [7]. This study aims to systematically compare the clinical efficacy of single-tube drainage, double-tube drainage, and double-tube drainage with delayed low-negative pressure in stage III tuberculous empyema patients. By providing empirical evidence, we seek to optimize postoperative management, reduce complications, and improve recovery outcomes.

Methodology

This retrospective analysis included patients diagnosed with stage III tuberculous empyema who underwent single-port thoracoscopic decortication and closed chest drainage at Nanjing Second Hospital between January 2019 and January 2024. All procedures were conducted by a consistent thoracic surgery team to ensure uniformity in technique and minimize operator-dependent variability. The study received approval from the Ethics Committee of Nanjing Second Hospital (Approval No: [2023-LS-ky015]). Due to its retrospective design, the requirement for written informed consent was waived, and all patient data were anonymized in compliance with the Declaration of Helsinki and local ethical regulations.

Patients were positioned in a lateral decubitus position under general anesthesia. Single-lung ventilation was established through intravenous induction and double-lumen endotracheal intubation. A 3.0 cm incision was made in the fifth intercostal space between the anterior and mid-axillary lines. Thoracoscopic visualization facilitated the separation of pleural adhesions, drainage of purulent collections, and decortication of fibrotic tissue. Hemostasis was achieved, followed by irrigation of the pleural cavity with warm saline. In cases of bronchopleural fistula, repairs were performed using 4-0 polyglactin (Vicryl) sutures, reinforced with adjacent soft tissue coverage to enhance sealing and prevent recurrence.

Based on the postoperative drainage approach, patients were assigned to one of three groups (Figure 1):

- Single-Tube group: A single 28Fr chest tube was inserted at the pleural apex via the thoracoscopic observation port and connected to a water-sealed drainage system.
- Double-Tube group: Two 28Fr chest tubes were placed—one in the anterior pleural cavity and one in the posterior—both connected to a water-sealed system.
- Double-NP group: Two 28Fr tubes were similarly positioned, but from postoperative day 2, the anterior tube was connected to a negative pressure drainage system set at -8 to -10 cm H_2O, while the posterior tube remained on water seal.

Intraoperative intercostal nerve blocks were administered to all patients to reduce postoperative pain. A standardized pain management protocol was followed: 40 mg parecoxib sodium was administered intravenously every 12 hours for the first 48 hours, with subsequent doses adjusted based on pain severity and transitioned to oral celecoxib as needed. Pain intensity was evaluated using the Visual Analogue Scale (VAS) on postoperative days 1, 3, and 5, with scores recorded by trained nursing staff during routine assessments.

Postoperative care encompassed chest tube monitoring, respiratory physiotherapy, and infection prevention measures. Chest X-rays were obtained on postoperative day 1 to assess tube placement and initial lung expansion, followed by Computed Tomography (CT) scans on day 4 to evaluate pleural cavity clearance and lung re-expansion. Chest tubes were removed when the following criteria were met: absence of air leaks, drainage volume < 50 mL/day for three consecutive days, and no evidence of residual air or fluid on imaging. Patients were observed for 24 hours post-removal and discharged if no adverse events occurred. Follow-up CT scans at 1 and 4 months assessed long-term lung function recovery and pleural integrity.

Statistical analyses were conducted using R

Figure 1. Drainage Methods for Empyema. A. Single Drain: Single chest tube setup. B. Double Drain: Two-tube configuration. C. Negative Pressure: System with -8 cm H_2O suction.

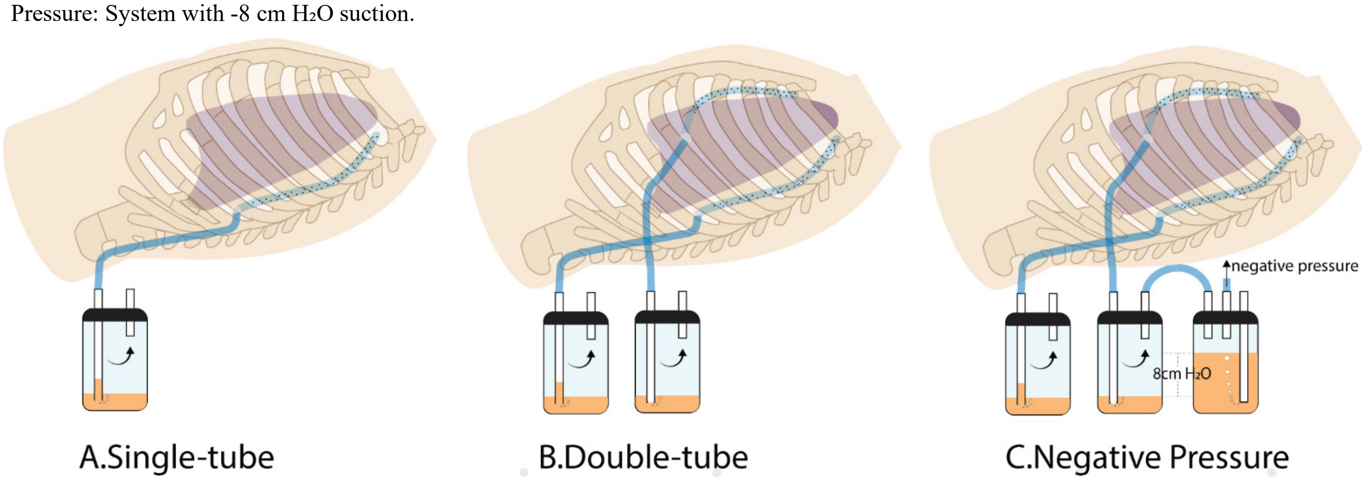


Table 1. Preoperative and Intraoperative Patient Characteristics.

Characteristics	Groups			Statistical Values	
	Single-tube Group (n = 42)	Double-tube Group (n = 51)	Negative Pressure Group (n = 131)	*F or χ2*	*p*
Age (yrs)	37.5 ± 11.4	39.1 ± 10.6	38.5 ± 12.1	0.202	0.817
Gender (M/F)	30/12	41/10	102/29	1.120	0.570
BMI (kg/m^2)	21.3 ± 2.3	21.0 ± 2.1	21.0 ± 1.8	0.342	0.711
Pus Cavity (R/L)	29/13	30/21	83/48	1.040	0.600
Hemoglobin (g/L)	125 ± 16.3	123 ± 18.7	126 ± 16.6	0.425	0.654
Albumin (g/L)	41.4 ± 3.9	40.8 ± 3.8	41.8 ± 3.5	1.242	0.291
FVC (% pred.)	69.7 (63.1–75.0)	73.0 (65.3–76.9)	70.6 (62.9–77.6)	1.314	0.518
FEV1 (% pred.)	67.7 (61.1–73.0)	71.2 (63.5–75.1)	68.6 (60.9–75.6)	1.450	0.484
DLco (% pred.)	63.3 (52.2–69.2)	59.1 (54.3–65.2)	59.0 (52.1–69.1)	1.157	0.561
Op Time (min)	246 ± 67.2	240 ± 64.7	234 ± 70.2	0.544	0.581
Blood loss (mL)	327 ± 123	360 ± 106	335 ± 122	1.089	0.338
Pus Vol. (mL)	216 ± 57.3	206 ± 60.9	224 ± 64.0	1.691	0.200

All continuous data are presented as mean ± standard deviation (SD) for normally distributed variables and as median (interquartile range, IQR) for non-normally distributed variables. Categorical data are presented as percentages with frequency counts in parentheses. Statistical comparisons among the groups were made using one-way analysis of variance (ANOVA) for continuous variables and chi-square tests (or Fisher's exact test where appropriate) for categorical variables. Statistical significance was set at $p < 0.05$.

software (v4.4.1). Continuous variables were tested for normality with the Shapiro-Wilk test and reported as mean ± Standard Deviation (SD) (normal) or median (Interquartile Range (IQR)) (non-normal). Categorical variables were expressed as n (%). Homogeneity of variance was assessed with Levene's test; homogeneous data were analyzed with ANOVA, and heterogeneous data with Welch's ANOVA ($p < 0.05$), followed by Student-Newman-Keuls q Test (SNK-q) post-hoc tests. Categorical data were compared using chi-square or Fisher's exact tests (two-tailed, $\alpha = 0.05$). A priori power analysis via the "pwr" package (Cohen's $f = 0.25$ for ANOVA, $w = 0.3$ for chi-square) confirmed adequate sample size. Multivariate regression assessed the impact of drainage strategy and covariates (Body Mass Index (BMI), age, sex, empyema location, operative time, blood loss) on outcomes, using linear regression for continuous outcomes and logistic regression for binary outcomes.

Results

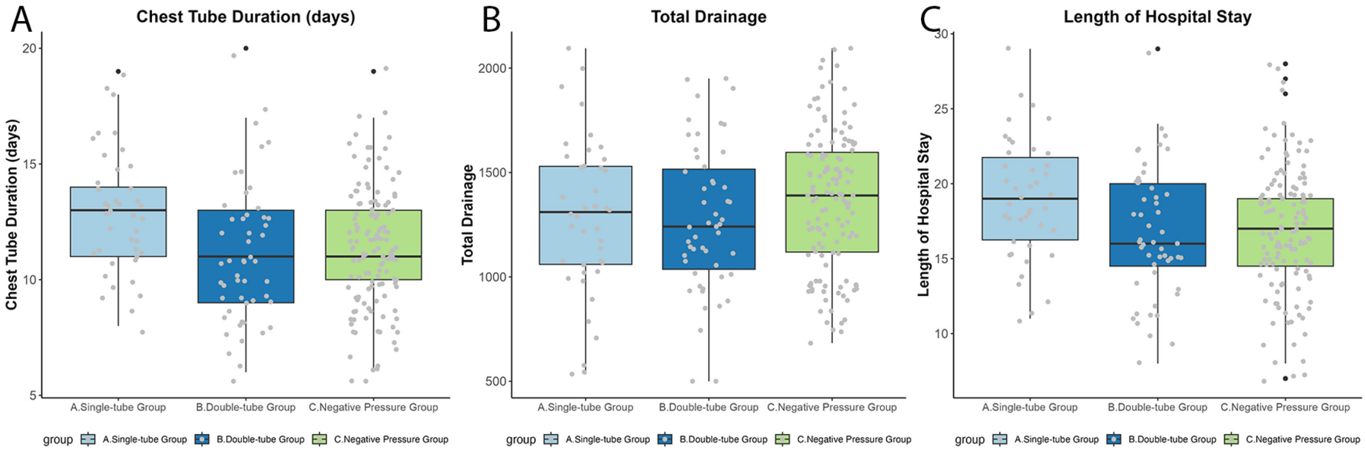
The study enrolled 224 stage III tuberculous empyema patients undergoing single-port thoracoscopic decortication, categorized into the Single-Tube group (n = 42), Double-Tube group (n = 51), and Double-NP group (n = 131). Baseline demographics and clinical characteristics—including age (Single-Tube: 37.5 ± 9.2 years; Double-Tube: 39.1 ± 10.3 years; Double-NP: 38.5 ± 9.8 years), sex distribution, BMI, empyema location, preoperative hemoglobin, albumin, forced vital capacity (FVC%pred), forced expiratory volume in 1 second

Table 2. Postoperative Drainage Outcomes and Complication Rates.

Characteristics	Groups			Statistical Values	
	Single-Tube Group (n = 42)	Double-Tube Group (n = 51)	Double-NP Group (n = 131)	*F or χ2*	*p*
Drainage Vol. (mL)					
Postop Day 1	372 ± 141	359 ± 146	346 ± 147	0.539	0.584
Postop Day 2	219 ± 79	214 ± 64	231 ± 75	1.180	0.309
Total	1285 ± 372	1276 ± 349	1364 ± 331	1.636	0.197
Drain & LOS (days)					
Removal Time	12.9 ± 2.6	11.1 ± 3.1[a]	11.3 ± 2.6[a]	6.055	0.003[*]
Hospital Stay	19.0 ± 4.0	16.7 ± 4.3[a]	16.9 ± 4.2[a]	4.471	0.013[*]
Postoperative Complications					
Atelectasis (%)	28.6 (12/42)	21.6 (11/51)	10.6 (13/131)[ab]	9.679	0.008[*]
Pleural Effusion (%)	21.4 (9/42)	19.6 (10/51)	7.6 (10/131)[a]	7.970	0.019[*]
Pneumothorax (%)	19.0 (8/42)	13.7 (7/51)	4.6 (6/131)[ab]	9.306	0.010[*]
Prolonged Air Leak (%)	54.8 (23/42)	49.0 (25/51)	29.8 (39/131)[ab]	11.243	0.004[*]
Drainage Reinsert (%)	21.4 (9/42)	7.8 (4/51)[a]	4.6 (6/131)[a]	11.665	0.003[*]
Pain Score (VAS)					
Postop Day 1	39.6 ± 13.5	34.8 ± 16.0	34.7 ± 14.4	1.902	0.152
Postop Day 3	29.4 ± 11.6	37.3 ± 14.1[a]	34.4 ± 11.3[a]	5.032	0.007[*]
Postop Day 5	26.3 ± 11.5	34.5 ± 10.1[a]	30.4 ± 11.0[a]	6.494	0.002

All continuous data are presented as mean ± standard deviation (SD). Categorical data, including atelectasis, pleural effusion, pneumothorax, prolonged air leak, and drainage reinsertion, are presented as percentages with frequency counts in parentheses. Statistical comparisons between the groups were made using one-way analysis of variance (ANOVA) for continuous variables and chi-square tests (or Fisher's exact test where appropriate) for categorical variables. Statistical significance was defined as $p < 0.05$. [a]: Statistical differences were observed when compared to the Single-tube Group; [b]: Statistical differences were observed when compared to the Double-tube Group; [*]: Statistical significance was set at $p < 0.05$.

Figure 2. Postoperative Outcomes by Drainage Strategy. A. Chest Tube Duration: Duration in days for each drainage group. B. Total Drainage: Total fluid drained (mL) per group. C. Length of Hospital Stay: Hospital stay duration in days for each group.

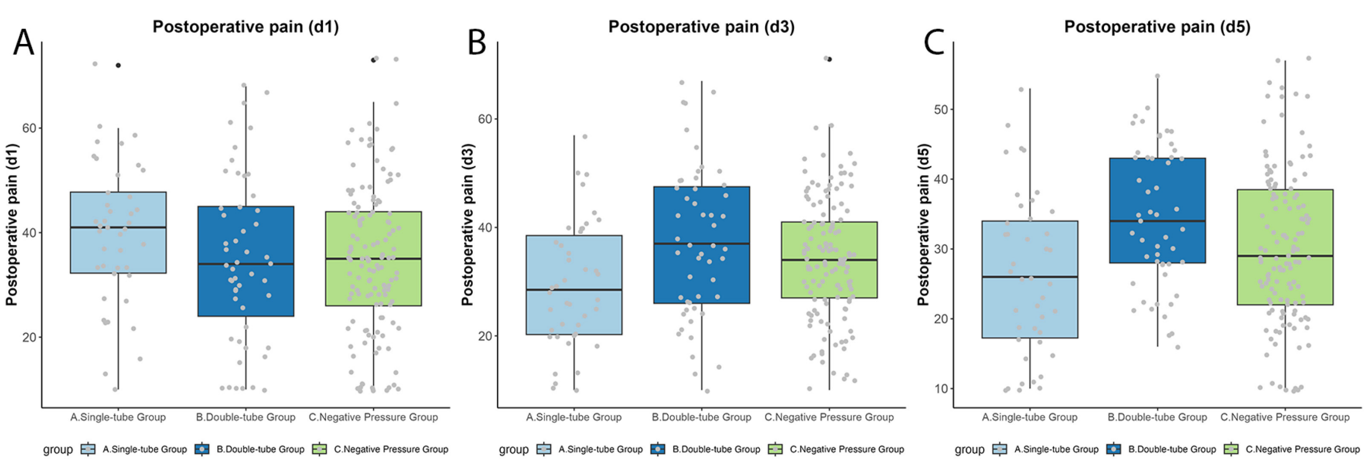


(FEV₁%pred), diffusing capacity for carbon monoxide (Diffusing Capacity for Carbon Monoxide, Percent Predicted (DLco%pred)), operative time, intraoperative blood loss, and initial pleural effusion volume—demonstrated no statistically significant differences across groups ($p > 0.05$, Table 1). This homogeneity ensures that observed outcome differences are attributable to the drainage strategies rather than confounding variables.

Postoperative drainage volumes on days 1 and 2, as well as cumulative totals, were comparable across all groups ($p > 0.05$, Table 2), suggesting that drainage capacity per se did not vary significantly with tube number or pressure application. However, significant differences emerged in chest tube duration and hospital stay. The Double-NP group (11.3 ± 2.6 days) and Double-Tube group (11.1 ± 3.1 days) exhibited shorter chest tube durations than the Single-Tube group (12.9 ± 2.6 days) (F = 6.055, $p = 0.003$). Similarly, hospital stays were reduced in the Double-NP (16.9 ± 4.2 days) and Double-Tube (16.7 ± 4.3 days) groups compared to the Single-Tube group (19.0 ± 4.0 days) (F = 4.471, $p = 0.013$) (Table 2, Figure 2). These findings indicate that multi-tube configurations, particularly with negative pressure, expedite pleural clearance and recovery.

Complication profiles further differentiated the groups. Chest tube reinsertion rates were significantly lower in the Double-NP (4.6%) and Double-Tube (7.8%) groups compared to the Single-Tube group (21.4%) ($\chi^2 = 11.665$, $p = 0.003$), reflecting fewer instances of inadequate drainage or persistent complications requiring intervention. Persistent air leaks, occurring in 38.8% of the cohort overall, were less frequent in the Double-NP group (29.8%) than in the Single-Tube (54.8%) and Double-Tube (49.0%) groups ($\chi^2 = 11.243$, $p = 0.004$). The Double-NP group also demonstrated significantly reduced incidences of pleural effusion (8.4% vs. 23.8% in Single-Tube), atelectasis (6.1% vs. 19.0% in Single-Tube), and pneumothorax (3.8% vs. 14.3% in Single-Tube) (all $p <$

Figure 3. Postoperative Pain Scores Over Time. A. Day 1: No significant difference across groups. B. Day 3: Single-Tube group shows lower scores than other groups. C. Day 5: Single-Tube group maintains lower scores compared to others.



0.01, Table 2). These data underscore the protective effect of combined tube placement and negative pressure in minimizing postoperative morbidity.

Pain outcomes revealed a trade-off. On postoperative day 1, VAS scores were similar across groups ($p > 0.05$), likely due to uniform nerve block and early analgesia. However, by days 3 and 5, the Single-Tube group reported lower scores (29.3 ± 11.6 and 26.3 ± 11.5) compared to the Double-Tube (37.3 ± 14.1 and 34.5 ± 10.1) and Double-NP (34.4 ± 11.3 and 30.4 ± 11.0) groups ($p < 0.01$, Figure 3). This suggests that while multi-tube strategies enhance drainage efficiency, they may increase pleural irritation or discomfort, necessitating enhanced pain management.

Multivariate linear regression identified higher BMI as a predictor of increased day 1 drainage ($p < 0.05$), possibly due to greater tissue trauma or fluid dynamics in obese patients. Drainage strategy significantly influenced chest tube duration, hospital stay, and pain scores on days 3 and 5 ($p < 0.05$); compared to the Single-Tube group, the Double-Tube and Double-NP groups exhibited shorter durations and stays but higher pain levels. Logistic regression confirmed the protective effects of the Double-NP strategies against prolonged air leaks (Odds Ratio (OR) = 0.142, $p < 0.01$) and atelectasis (OR = 0.231, $p < 0.01$). In the pneumothorax model, lower event rates in these groups resulted in unstable odds ratios, warranting cautious interpretation (Supplementary Table 1,2).

Discussion

Chest drainage is integral to postoperative thoracic surgery, serving to evacuate pleural contents, maintain negative pressure, and facilitate lung re-expansion [8]. Its efficacy directly influences complication rates—persistent pneumothorax, pleural effusion, atelectasis, and infection—and patient recovery trajectories [9]. In stage III tuberculous empyema, the thickened pleura, multiloculated cavities, and viscous pus create a uniquely challenging postoperative environment. Traditional single-tube drainage often falls short, struggling to address the extensive and irregular pleural surfaces, which increases treatment complexity and complication risks [1].

Single-tube drainage is limited by its narrow coverage, particularly in cases with uneven fluid or air distribution. Residual collections can delay lung re-expansion, while significant air leaks overwhelm single-tube capacity, destabilizing pleural pressure and potentially inducing complications like localized positive pressure or pneumothorax [7,10,11]. These deficiencies are magnified in stage III tuberculous empyema, where compartmentalized cavities and encapsulated effusions demand comprehensive drainage beyond single-tube capabilities, often prolonging recovery and elevating morbidity.

To address these challenges, we developed a “double-tube with delayed low-negative-pressure drainage strategy.” This approach leverages dual tubes to broaden pleural coverage and incorporates low negative pressure (-8 to -10 cm H_2O) starting on postoperative day 2 to enhance efficacy while minimizing risks. The double-tube setup targets both anterior and posterior pleural regions, creating a multi-directional drainage network that effectively clears multiloculated effusions and air. This “stereoscopic” drainage model is particularly advantageous in extensive decortication cases, reducing residual pathology and mitigating risks of prolonged air leaks or infections [5,12]. Observational studies and clinical observations suggest that multi-tube configurations may improve outcomes in complex pleural effusions and empyema by enhancing pleural clearance, particularly in cases with loculations [13,14], though systematic reviews specifically addressing this approach remain limited.

The delayed negative pressure component is equally strategic. Immediate postoperative application of suction in stage III empyema risks exacerbating bleeding and fluid loss due to raw pleural surfaces and ongoing exudation, potentially leading to hemodynamic instability or electrolyte disturbances. Delaying negative pressure until day 2 allows initial stabilization and clot formation, reducing hemorrhage risks while enabling controlled suction to maintain pleural negativity and promote lung re-expansion once primary drainage is achieved. The selected pressure range (-8 to -10 cm H_2O) aligns with physiological pleural dynamics, avoiding tissue damage, increased bleeding, or reduced lung compliance associated with higher pressures [10,15]. This approach is supported by prospective trials in lung resection, which demonstrate that low negative pressure is both safe and effective, with minimal adverse effects on bleeding or recovery [16,17].

This study demonstrates that the double-tube with delayed low-negative-pressure drainage strategy outperforms traditional single-tube drainage in the postoperative management of stage III tuberculous empyema. Specifically, it significantly reduces chest tube duration (11.3 ± 2.6 days vs. 12.9 ± 2.6 days, $p = 0.003$), hospital stay (16.9 ± 4.2 days vs. 19.0 ± 4.0 days, $p = 0.013$), and complication rates, including persistent air leak (29.8% vs. 54.8%, $p = 0.004$).

Multivariate regression analysis confirms that the drainage strategy significantly influences chest tube duration, hospital stay, and complications (e.g., persistent air leak, OR = 0.47, $p = 0.012$), with higher BMI correlating with increased early postoperative drainage ($p = 0.0215$). However, the double-tube and negative-pressure groups exhibited higher VAS pain scores on postoperative days 3 and 5 (34.4 ± 11.3 vs. 29.3 ± 11.6, $p < 0.01$), indicating a need for enhanced pain management.

Despite its promising results, this study has limitations. As a single-center, small-sample observational study, its statistical power, and generalizability may be limited, necessitating larger, multicenter RCTs to validate safety and efficacy. Follow-up focused on short-term outcomes (e.g., chest tube duration, hospital stay), with insufficient evaluation of long-term prognosis (e.g., lung function, quality of life, chronic pain), offering avenues for future research. Additionally, reliance on traditional water-sealed systems limits the precision of drainage data; digital drainage systems, offering real-time air leak and drainage metrics [18–20], could enhance decision-making accuracy in future applications.

Conclusions

The double-tube with delayed low-negative-pressure drainage strategy offers a novel approach to postoperative chest drainage in stage III tuberculous empyema. By expanding drainage coverage, optimizing negative pressure timing, and refining pressure settings, it improves pathological clearance, reduces complications, promotes lung re-expansion, and shortens hospital stays. While limitations remain, these preliminary findings lay a foundation for advancing and standardizing chest drainage techniques.

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Conflict of interest

No conflict of interest is declared.

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Annex – Supplementary Items

Supplementary Table 1. Multivariate Linear Regression Model Results.

(A) Hosp. Stay (Length of Hospital Stay).

Characteristics	Estimate	Std. Error	t value	*p*
Intercept	11.496	6.747	1.704	0.090
group2 (vs group1)	-2.675	0.960	-2.788	0.006 **
group3 (vs group1)	-2.294	0.868	-2.642	0.009 **
Age (yrs)	0.012	0.025	0.496	0.621
Gender (M/F)	-0.662	0.664	-0.997	0.320
BMI (kg/m2)	0.102	0.149	0.682	0.496
Pus Cavity (R/L)	-0.079	0.614	-0.128	0.898
Hemoglobin (g/L)	0.004	0.017	0.228	0.820
Albumin (g/L)	0.081	0.080	1.014	0.311
FVC (% pred.)	-0.002	0.042	-0.043	0.965
FEV1 (% pred.)	-0.018	0.034	-0.526	0.599
DLco (% pred.)	-0.093	0.040	-2.303	0.022 *
Op Time (min)	0.001	0.004	0.210	0.834
Blood loss (mL)	0.004	0.002	1.670	0.096
Pus Vol. (mL)	0.002	0.005	0.370	0.711

***p < 0.001, **p < 0.01, *p < 0.05. 1 Drainage Strategy. The Single-Tube group (group1) served as the reference, compared against the Double-Tube group (group2) and the Double-NP group (group3). Refer to the Methods section for group definitions. CI = Confidence Interval. 2 Gender (Male vs. Female). Female served as the reference group, with Male as the comparison group. 3 Pus Cavity Location (Right vs. Left). Left side served as the reference group, with Right side as the comparison group.

(B) Total (Drainage Vol. (mL)).

Characteristics	Estimate	Std. Error	t value	*p*
Intercept	551.772	550.956	1.001	0.318
group2 (vs group1)	-38.194	78.368	-0.487	0.627
group3 (vs group1)	46.902	70.907	0.661	0.509
Age (yrs)	0.670	2.011	0.333	0.739
Gender (M/F)	-44.155	54.197	-0.815	0.416
BMI (kg/m2)	21.353	12.173	1.754	0.081
Pus Cavity (R/L)	-44.355	50.153	-0.884	0.378
Hemoglobin (g/L)	0.791	1.404	0.564	0.574
Albumin (g/L)	-5.199	6.511	-0.799	0.425
FVC (% pred.)	4.030	3.418	1.179	0.240
FEV1 (% pred.)	-1.651	2.777	-0.595	0.553
DLco (% pred.)	2.987	3.293	0.907	0.365
Op Time (min)	0.121	0.349	0.346	0.730
Blood loss (mL)	0.304	0.200	1.520	0.130
Pus Vol. (mL)	-0.084	0.380	-0.221	0.825

***p < 0.001, **p < 0.01, *p < 0.05. 1 Drainage Strategy. The Single-Tube group (group1) served as the reference, compared against the Double-Tube group (group2) and the Double-NP group (group3). Refer to the Methods section for group definitions. CI = Confidence Interval. 2 Gender (Male vs. Female). Female served as the reference group, with Male as the comparison group. 3 Pus Cavity Location (Right vs. Left). Left side served as the reference group, with Right side as the comparison group.

(C) Postop Day 0 (Drainage Vol. (mL)).

Characteristics	Estimate	Std. Error	t value	*p*
Intercept	-78.001	231.543	-0.337	0.737
group2 (vs group1)	-24.705	32.935	-0.750	0.454
group3 (vs group1)	-40.583	29.799	-1.362	0.175
Age (yrs)	0.471	0.845	0.557	0.578
Gender (M/F)	-12.932	22.776	-0.568	0.571
BMI (kg/m2)	12.602	5.116	2.463	0.015 *
Pus Cavity (R/L)	-13.059	21.077	-0.620	0.536
Hemoglobin (g/L)	0.025	0.590	0.043	0.966
Albumin (g/L)	-1.877	2.736	-0.686	0.494
FVC (% pred.)	2.101	1.437	1.469	0.143
FEV1 (% pred.)	-0.775	1.167	-0.664	0.507
DLco (% pred.)	2.291	1.384	1.656	0.099
Op Time (min)	-0.021	0.147	-0.141	0.888
Blood loss (mL)	0.153	0.084	1.820	0.070
Pus Vol. (mL)	-0.038	0.160	-0.238	0.812

***p < 0.001, **p < 0.01, *p < 0.05. 1 Drainage Strategy. The Single-Tube group (group1) served as the reference, compared against the Double-Tube group (group2) and the Double-NP group (group3). Refer to the Methods section for group definitions. CI = Confidence Interval. 2 Gender (Male vs. Female). Female served as the reference group, with Male as the comparison group. 3 Pus Cavity Location (Right vs. Left). Left side served as the reference group, with Right side as the comparison group.

(D) Postop Day 1 (Drainage Vol. (mL)).

Characteristics	Estimate	Std. Error	t value	*p*
Intercept	92.646	89.426	1.036	0.301
group2 (vs group1)	-9.493	16.987	-0.559	0.577
group3 (vs group1)	10.744	15.370	0.699	0.485
Age (yrs)	-0.087	0.436	-0.200	0.842
Gender (M/F)	-1.613	11.748	-0.137	0.891
BMI (kg/m2)	-4.079	2.639	-1.546	0.124
Pus Cavity (R/L)	-9.720	10.871	-0.894	0.372
Hemoglobin (g/L)	0.283	0.304	0.932	0.353
Albumin (g/L)	-0.478	1.411	-0.338	0.735
FVC (% pred.)	-0.584	0.741	-0.788	0.432
FEV1 (% pred.)	-0.069	0.602	-0.115	0.909
DLco (% pred.)	-0.170	0.714	-0.239	0.812
Op Time (min)	0.050	0.076	0.662	0.508
Blood loss (mL)	-0.003	0.043	-0.072	0.942
Pus Vol. (mL)	-0.015	0.082	-0.186	0.853

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$. 1 Drainage Strategy. The Single-Tube group (group1) served as the reference, compared against the Double-Tube group (group2) and the Double-NP group (group3). Refer to the Methods section for group definitions. CI = Confidence Interval. 2 Gender (Male vs. Female). Female served as the reference group, with Male as the comparison group. 3 Pus Cavity Location (Right vs. Left). Left side served as the reference group, with Right side as the comparison group.

(E) Drain Removal Time (days).

Characteristics	Estimate	Std. Error	t value	*p*
Intercept	11.755	14.318	0.821	0.413
group2 (vs group1)	-2.014	0.614	-3.278	0.001 **
group3 (vs group1)	-1.716	0.556	-3.088	0.002 **
Age (yrs)	0.011	0.016	0.682	0.496
Gender (M/F)	-0.386	0.425	-0.909	0.365
BMI (kg/m2)	0.052	0.095	0.548	0.584
Pus Cavity (R/L)	-0.216	0.393	-0.549	0.584
Hemoglobin (g/L)	0.003	0.011	0.285	0.776
Albumin (g/L)	0.051	0.051	0.996	0.321
FVC (% pred.)	0.004	0.027	0.159	0.874
FEV1 (% pred.)	-0.010	0.022	-0.463	0.644
DLco (% pred.)	-0.036	0.026	-1.381	0.169
Op Time (min)	3.898e-04	0.003	0.142	0.887
Blood loss (mL)	0.003	0.002	1.662	0.098
Pus Vol. (mL)	0.002	0.003	0.562	0.575

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$. 1 Drainage Strategy. The Single-Tube group (group1) served as the reference, compared against the Double-Tube group (group2) and the Double-NP group (group3). Refer to the Methods section for group definitions. CI = Confidence Interval. 2 Gender (Male vs. Female). Female served as the reference group, with Male as the comparison group. 3 Pus Cavity Location (Right vs. Left). Left side served as the reference group, with Right side as the comparison group.

(F) Postop Day 1 Pain Score (VAS).

Characteristics	Estimate	Std. Error	t value	*p*
Intercept	37.653	23.322	1.614	0.108
group2 (vs group1)	-2.168	3.317	-0.653	0.514
group3 (vs group1)	-1.551	3.001	-0.517	0.606
Age (yrs)	-0.050	0.085	-0.592	0.555
Gender (M/F)	-1.982	2.294	-0.864	0.389
BMI (kg/m2)	-0.436	0.515	-0.846	0.398
Pus Cavity (R/L)	3.643	2.123	1.716	0.088
Hemoglobin (g/L)	0.019	0.059	0.317	0.751
Albumin (g/L)	0.485	0.276	1.760	0.080
FVC (% pred.)	-0.232	0.145	-1.605	0.110
FEV1 (% pred.)	0.181	0.118	1.543	0.124
DLco (% pred.)	-0.087	0.139	-0.622	0.534
Op Time (min)	0.001	0.015	0.067	0.947
Blood loss (mL)	-0.003	0.008	-0.316	0.752
Pus Vol. (mL)	-0.015	0.016	-0.934	0.351

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$. 1 Drainage Strategy. The Single-Tube group (group1) served as the reference, compared against the Double-Tube group (group2) and the Double-NP group (group3). Refer to the Methods section for group definitions. CI = Confidence Interval. 2 Gender (Male vs. Female). Female served as the reference group, with Male as the comparison group. 3 Pus Cavity Location (Right vs. Left). Left side served as the reference group, with Right side as the comparison group.

(G) Postop Day 3 Pain Score (VAS).

Characteristics	Estimate	Std. Error	t value	*p*
Intercept	37.653	23.322	1.614	0.108
group2 (vs group1)	-7.806	3.317	-2.353	0.020 *
group3 (vs group1)	-7.555	3.001	-2.517	0.013*
Age (yrs)	-0.050	0.085	-0.592	0.555
Gender (M/F)	-1.982	2.294	-0.864	0.389
BMI (kg/m2)	-0.436	0.515	-0.846	0.398
Pus Cavity (R/L)	3.643	2.123	1.716	0.088
Hemoglobin (g/L)	0.019	0.059	0.317	0.751
Albumin (g/L)	0.485	0.276	1.760	0.080
FVC (% pred.)	-0.232	0.145	-1.605	0.110
FEV1 (% pred.)	0.181	0.118	1.543	0.124
DLco (% pred.)	-0.087	0.139	-0.622	0.534
Op Time (min)	0.001	0.015	0.067	0.947
Blood loss (mL)	-0.003	0.008	-0.316	0.752
Pus Vol. (mL)	-0.015	0.016	-0.934	0.351

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$. 1 Drainage Strategy. The Single-Tube group (group1) served as the reference, compared against the Double-Tube group (group2) and the Double-NP group (group3). Refer to the Methods section for group definitions. CI = Confidence Interval. 2 Gender (Male vs. Female). Female served as the reference group, with Male as the comparison group. 3 Pus Cavity Location (Right vs. Left). Left side served as the reference group, with Right side as the comparison group.

(H) Postop Day 5 Pain Score (VAS).

Characteristics	Estimate	Std. Error	t value	*p*
Intercept	-17.791	17.23	-1.032	0.303
group2 (vs group1)	6.578	2.451	3.460	0.007 **
group3 (vs group1)	5.720	2.218	2.579	0.011 *
Age (yrs)	-0.097	0.063	-1.545	0.124
Gender (M/F)	-0.504	1.695	-0.298	0.766
BMI (kg/m2)	0.327	0.381	0.860	0.391
Pus Cavity (R/L)	-0.332	1.569	-0.212	0.833
Hemoglobin (g/L)	0.035	4.390	0.791	0.430
Albumin (g/L)	0.222	0.204	1.088	0.278
FVC (% pred.)	0.046	0.107	0.435	0.664
FEV1 (% pred.)	-0.036	0.087	-0.418	0.677
DLco (% pred.)	0.190	0.103	1.845	0.066
Op Time (min)	-8.903e-05	0.011	-0.008	0.994
Blood loss (mL)	0.003	0.006	0.409	0.683
Pus Vol. (mL)	-0.007	0.012	-0.623	0.534

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$. 1 Drainage Strategy. The Single-Tube group (group1) served as the reference, compared against the Double-Tube group (group2) and the Double-NP group (group3). Refer to the Methods section for group definitions. CI = Confidence Interval. 2 Gender (Male vs. Female). Female served as the reference group, with Male as the comparison group. 3 Pus Cavity Location (Right vs. Left). Left side served as the reference group, with Right side as the comparison group.

Supplementary Table 2. Logistic Regression Model Results.

(A) Drainage Reinsert (%).

Characteristics	Estimate	Std. Error	z value	OR (Odds Ratio)	95% CI	Pr (>|z|)
Intercept	0.145	4.052	0.036	1.156	[0.00039, 3330.23]	0.972
group2 (vs group1)	0.102	0.526	0.194	1.108	[0.396, 3.154]	0.846
group3 (vs group1)	-0.521	0.490	-1.064	0.594	[0.228, 1.576]	0.287
Age (yrs)	4.888e-4	0.015	0.033	1.000	[0.971, 1.030]	0.974
Gender (M/F)	-0.102	0.399	-0.256	0.903	[0.420, 2.029]	0.798
BMI (kg/m2)	0.029	0.086	0.337	1.030	[0.868, 1.221]	0.736
Pus Cavity (R/L)	-0.016	0.377	-0.044	0.984	[0.473, 2.092]	0.965
Hemoglobin (g/L)	0.001	0.010	0.127	1.001	[0.981, 1.022]	0.899
Albumin (g/L)	-0.064	0.050	-1.285	0.938	[0.849, 1.032]	0.199
FVC (% pred.)	-0.032	0.026	-1.23	0.968	[0.919, 1.019]	0.219
FEV1 (% pred.)	0.034	0.021	1.621	1.034	[0.993, 1.078]	0.105
DLco (% pred.)	0.016	0.024	0.649	1.016	[0.969, 1.066]	0.517
Op Time (min)	0.003	0.003	1.129	1.003	[0.998, 1.008]	0.259
Blood loss (mL)	-0.002	0.001	-1.514	0.998	[0.995, 1.001]	0.130
Pus Vol. (mL)	-0.001	0.003	-0.502	0.999	[0.993, 1.004]	0.616

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$. 1 Drainage Strategy. The Single-Tube group (group1) served as the reference, compared against the Double-Tube group (group2) and the Double-NP group (group3). Refer to the Methods section for group definitions. CI = Confidence Interval. 2 Gender (Male vs. Female). Female served as the reference group, with Male as the comparison group. 3 Pus Cavity Location (Right vs. Left). Left side served as the reference group, with Right side as the comparison group.

(B) Pneumothorax (%).

Characteristics	Estimate	Std. Error	z value	OR (Odds Ratio)	95% CI	Pr (>|z|)
Intercept	1.02E+01	3.18E+01	0.32	26425.87	[1.14e-21, 5.44e+39]	0.749
group2 (vs group1)	-2.09E+01	5.37E+03	-0.004	8.22E-10	[NA, 6.04e+238]	0.997
group3 (vs group1)	-2.23E+01	3.05E+03	-0.007	2.18E-10	[NA, 4.61e+119]	0.994
Age (yrs)	1.08E-01	1.05E-01	1.025	1.114	[0.928, 1.503]	0.305
Gender (M/F)	-2.08E+00	2.37E+00	-0.881	0.124	[5.58e-05, 6.263]	0.378
BMI (kg/m2)	-2.84E-01	4.77E-01	-0.597	0.752	[0.244, 1.917]	0.551
Pus Cavity (R/L)	-2.67E+00	3.17E+00	-0.843	0.069	[9.10e-06, 27.75]	0.399
Hemoglobin (g/L)	3.34E-02	6.78E-02	0.492	1.034	[0.914, 1.242]	0.623
Albumin (g/L)	-6.03E-01	5.12E-01	-1.177	0.547	[0.098, 1.081]	0.239
FVC (% pred.)	-7.58E-02	1.99E-01	-0.382	0.927	[0.530, 1.338]	0.703
FEV1 (% pred.)	8.12E-02	9.15E-02	0.887	1.085	[0.930, 1.473]	0.375
DLco (% pred.)	1.95E-01	1.41E-01	1.385	1.215	[0.992, 1.969]	0.166
Op Time (min)	5.15E-04	1.06E-02	0.048	1.0005	[0.979, 1.029]	0.961
Blood loss (mL)	1.01E-03	6.67E-03	0.152	1.001	[0.987, 1.016]	0.879
Pus Vol. (mL)	-4.80E-03	2.52E-02	-0.19	0.995	[0.934, 1.049]	0.849

The relatively low incidence of pneumothorax in our study raises concerns about potential complete or quasi-complete separation in the logistic regression model. Consequently, the current model may not provide reliable evidence regarding the relationship between the investigated factors and the risk of pneumothorax. 1 Drainage Strategy. The Single-Tube group (group1) served as the reference, compared against the Double-Tube group (group2) and the Double-NP group (group3). Refer to the Methods section for group definitions. CI = Confidence Interval. 2 Gender (Male vs. Female). Female served as the reference group, with Male as the comparison group. 3 Pus Cavity Location (Right vs. Left). Left side served as the reference group, with Right side as the comparison group.

(C) Atelectasis (%).

Characteristics	Estimate	Std. Error	z value	OR (Odds Ratio)	95% CI	Pr (>|z|)
Intercept	-1.04E+00	4.37E+00	-0.238	0.354	[6.22e-05, 1890.52]	0.812
group2 (vs group1)	-8.93E-01	5.55E-01	-1.611	0.409	[0.134, 1.200]	0.107
group3 (vs group1)	-1.46E+00	5.14E-01	-2.847	0.231	[0.083, 0.629]	0.004 **
Age (yrs)	-5.45E-03	1.64E-02	-0.333	0.995	[0.963, 1.027]	0.739
Gender (M/F)	-1.99E-01	4.20E-01	-0.474	0.82	[0.367, 1.927]	0.636
BMI (kg/m2)	-4.61E-02	9.41E-02	-0.49	0.955	[0.791, 1.146]	0.624
Pus Cavity (R/L)	3.85E-01	4.24E-01	0.909	1.47	[0.655, 3.500]	0.364
Hemoglobin (g/L)	7.15E-03	1.13E-02	0.632	1.007	[0.985, 1.030]	0.528
Albumin (g/L)	-2.43E-03	5.14E-02	-0.047	0.998	[0.901, 1.103]	0.962
FVC (% pred.)	2.05E-03	2.76E-02	0.074	1.002	[0.949, 1.059]	0.941
FEV1 (% pred.)	-1.72E-02	2.15E-02	-0.801	0.983	[0.942, 1.025]	0.423
DLco (% pred.)	1.77E-02	2.53E-02	0.7	1.018	[0.969, 1.071]	0.484
Op Time (min)	-6.25E-04	2.80E-03	-0.223	0.9994	[0.994, 1.005]	0.823
Blood loss (mL)	-4.25E-05	1.62E-03	-0.026	1.00005	[0.997, 1.003]	0.979
Pus Vol. (mL)	3.95E-03	3.07E-03	1.288	1.004	[0.998, 1.010]	0.198

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$. 1 Drainage Strategy. The Single-Tube group (group1) served as the reference, compared against the Double-Tube group (group2) and the Double-NP group (group3). Refer to the Methods section for group definitions. CI = Confidence Interval. 2 Gender (Male vs. Female). Female served as the reference group, with Male as the comparison group. 3 Pus Cavity Location (Right vs. Left). Left side served as the reference group, with Right side as the comparison group.

(D) Pleural Effusion (%).

Characteristics	Estimate	Std. Error	z value	OR (Odds Ratio)	95% CI	Pr (>|z|)
Intercept	-2.275	4.206	-0.541	0.103	[2.43e-05, 381.64]	0.589
group2 (vs group1)	0.785	0.574	1.368	2.193	[0.729, 7.040]	0.171
group3 (vs group1)	0.077	0.538	0.143	1.080	[0.385, 3.224]	0.886
Age (yrs)	-0.007	0.015	-0.438	0.993	[0.963, 1.024]	0.662
Gender (M/F)	0.090	0.421	0.213	1.094	[0.492, 2.598]	0.832
BMI (kg/m2)	0.073	0.090	0.813	1.076	[0.901, 1.285]	0.417
Pus Cavity (R/L)	0.026	0.386	0.067	1.026	[0.486, 2.231]	0.946
Hemoglobin (g/L)	-0.001	0.011	-0.115	0.999	[0.978, 1.020]	0.909
Albumin (g/L)	-0.037	0.051	-0.732	0.963	[0.870, 1.063]	0.464
FVC (% pred.)	-0.025	0.027	-0.935	0.975	[0.925, 1.028]	0.35
FEV1 (% pred.)	0.030	0.022	1.393	1.031	[0.988, 1.076]	0.164
DLco (% pred.)	0.007	0.025	0.293	1.007	[0.959, 1.059]	0.77
Op Time (min)	0.003	0.003	1.267	1.003	[0.998, 1.009]	0.205
Blood loss (mL)	-0.003	0.002	-1.687	0.997	[0.994, 1.000]	0.092
Pus Vol. (mL)	0.001	0.003	0.174	1.001	[0.995, 1.006]	0.862

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$. 1 Drainage Strategy. The Single-Tube group (group1) served as the reference, compared against the Double-Tube group (group2) and the Double-NP group (group3). Refer to the Methods section for group definitions. CI = Confidence Interval. 2 Gender (Male vs. Female). Female served as the reference group, with Male as the comparison group. 3 Pus Cavity Location (Right vs. Left). Left side served as the reference group, with Right side as the comparison group.

(E) Prolonged air leak (%).

Characteristics	Estimate	Std. Error	z value	OR (Odds Ratio)	95% CI	Pr (>|z|)
Intercept	-3.11E+00	3.47E+00	-0.895	0.045	[4.56e-05, 39.47]	0.371
group2 (vs group1)	-9.22E-01	4.93E-01	-1.87	0.398	[0.148, 1.032]	0.062
group3 (vs group1)	-1.95E+00	4.74E-01	-4.111	0.142	[0.054, 0.349]	3.94e-05 ***
Age (yrs)	-1.56E-02	1.30E-02	-1.200	0.985	[0.959, 1.010]	0.230
Gender (M/F)	-3.70E-01	3.38E-01	-1.093	0.691	[0.355, 1.343]	0.275
BMI (kg/m2)	-5.43E-02	7.64E-02	-0.710	0.947	[0.815, 1.101]	0.478
Pus Cavity (R/L)	-2.25E-01	3.18E-01	-0.709	0.798	[0.427, 1.487]	0.478
Hemoglobin (g/L)	1.08E-02	8.88E-03	1.213	1.011	[0.994, 1.029]	0.225
Albumin (g/L)	-6.00E-03	4.10E-02	-0.146	0.994	[0.917, 1.077]	0.884
FVC (% pred.)	5.48E-02	2.24E-02	2.447	1.056	[1.012, 1.105]	0.014 *
FEV1 (% pred.)	-4.30E-03	1.80E-02	-0.239	0.996	[0.961, 1.031]	0.811
DLco (% pred.)	2.00E-02	2.08E-02	0.963	1.020	[0.980, 1.063]	0.336
Op Time (min)	-3.21E-04	2.21E-03	-0.145	0.999	[0.995, 1.004]	0.885
Blood loss (mL)	4.53E-05	1.28E-03	0.035	1.000	[0.998, 1.003]	0.972
Pus Vol. (mL)	2.00E-03	2.40E-03	0.835	1.002	[0.997, 1.007]	0.404

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$. 1 Drainage Strategy. The Single-Tube group (group1) served as the reference, compared against the Double-Tube group (group2) and the Double-NP group (group3). Refer to the Methods section for group definitions. CI = Confidence Interval. 2 Gender (Male vs. Female). Female served as the reference group, with Male as the comparison group. 3 Pus Cavity Location (Right vs. Left). Left side served as the reference group, with Right side as the comparison group.