Impact and Predictors of Prolonged Chest Tube Duration in Mechanically Ventilated Patients with Acquired Pneumothorax

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BACKGROUND: Prolonged chest tube duration is less well studied in patients who are supported by mechanical ventilation and have acquired pneumothorax. We investigated the impact of prolonged chest tube duration on patient outcomes and the risk factors associated with prolonged chest tube duration. **METHODS:** This retrospective observational study included 106 ventilated subjects who had been treated with thoracostomy for pneumothorax between May 2004 and December 2011. We analyzed 61 subjects and 63 events. The subjects were divided into a prolonged chest tube duration group (> 18 d) and a non-prolonged group (≤ 18 d). **RESULTS:** Subjects with prolonged chest tube duration had significantly higher ICU mortality ($P = .006$), longer ICU stay ($P = .001$), longer hospitalization ($P = .004$), longer mechanical ventilation after development of pneumothorax ($P = .003$), higher maximum peak inspiratory pressure ($P = .03$), and a higher rate of surgical emphysema ($P = .009$). High peak inspiratory pressure and surgical emphysema remained independent predictors of prolonged chest tube duration after multivariate logistic regression analysis. The probability of chest tube removal within 28 days was significantly lower in subjects with both high peak inspiratory pressure and surgical emphysema, compared to subjects without any risk factors (log rank $P = .001$). **CONCLUSIONS:** High peak inspiratory pressure and surgical emphysema are independent predictors of prolonged chest tube duration and negatively impact clinical outcomes in this patient group. These findings may provide information for better chest tube management. *Key words:* pneumothorax; chest tube; thoracostomy; mechanical ventilation; subcutaneous emphysema; peak inspiratory pressure. [Respir Care 2013;58(12):2093–2100. © 2013 Daedalus Enterprises]

Introduction

Pneumothorax occurs in 4–15% of patients receiving mechanical ventilation, and is considered a medical emergency that requires prompt recognition and careful management.^{1,2} Thoracostomy with chest tube placement to relieve the life-threatening pneumothorax is mandatory for

these patients.^{1,2} Complications of tube thoracostomy include infection, tube malpositioning, laceration, and hemothorax, all of which may worsen outcome.^{3–9} Several studies have compared the safety and efficacy of different chest tube sizes^{3,10–12} and various methods of chest tube removal.^{13,14} Chest tube duration would seem to be an important management issue that might impact outcome, but there is a paucity of data on the impact of and risk factors affecting prolonged chest tube duration in patients with pneumothorax.

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The objectives of this study were to examine the impact of prolonged chest tube duration on outcomes in mechanically ventilated patients with acquired pneumothorax, and to identify the risk factors associated with prolonged chest tube duration in these patients. There is no consensus on what constitutes “prolonged” chest tube duration; we defined it as > 18 days, based on the median chest tube duration among the subjects in this study. Various comparisons were then performed of the prolonged group versus the non-prolonged group.

Methods

Design, Setting, and Subjects

This retrospective study was conducted in a 35-bed ICU at Taipei Veterans General Hospital, a 3,000-bed tertiary medical center. The study was registered with our institutional ethical review board (study 2012-03-007AC). The requirement for informed consent was waived, according to our institutional guidelines. Among the patients admitted to the ICU between May 2004 and December 2011, we identified those who had pneumothorax during mechanical ventilation, by searching for the International Classification of Diseases codes associated with pneumothorax (512.8) and respiratory failure (518.81) in the hospital’s electronic database. The inclusion criteria were: pneumothorax developed after initiation of mechanical ventilation; and pneumothorax treated with tube thoracostomy using 28 French chest tube and a suction pressure of 10–20 cm H₂O. The exclusion criteria were: chest tube duration could not be determined exactly; conditions (eg, empyema and hemothorax) requiring chest tube placement that may confound data collected during the subsequent development of pneumothorax; and transferred out of the ICU against the advice of the attending physician after the legal process of the request from the patient’s family.

Since there is no consensus on the definition of “prolonged” chest tube duration, we calculated the median chest tube duration among the subjects who successfully had their chest tubes removed during hospitalization, and divided the subjects into a prolonged chest tube duration group and a non-prolonged group, according to chest tube duration greater and not greater than the median value. Subjects who died before the median chest tube duration without chest tube removal were excluded because chest tube duration could not be evaluated.

Data Collection

Information was collected by careful chart review, using a data sheet specifically designed for this study. The hospital medical records, chest x-rays, and computed tomograms (CT) were reviewed. The following characteristics

QUICK LOOK

Current knowledge

Pneumothorax is a sudden and life-threatening complication of mechanical ventilation, and requires prompt placement of a thoracostomy tube. Tube size, method of placement, and method of removal all impact the chest tube duration required.

What this paper contributes to our knowledge

Prolonged chest tube duration in mechanically ventilated patients with iatrogenic pneumothorax was associated with higher mortality, longer duration of mechanical ventilation, and longer ICU and hospital stay. Surgical emphysema and a high peak inspiratory pressure within 24 hours after thoracostomy were independent predictors of prolonged chest tube duration.

were collected: age, sex, smoking status, comorbidities, cause requiring initiation of mechanical ventilation, Acute Physiology and Chronic Health Evaluation II score on ICU admission, and P_{aO₂}/F_{IO₂} on ICU admission. When pneumothorax occurred, the associated manifestations were also recorded, including location of pneumothorax; presence of concurrent septic shock; initial presentation (as either tension pneumothorax, procedure-related pneumothorax, or both); number of chest tubes; frequency of chest CT; surgical interventions; ventilator settings (including maximum tidal volume, minute ventilation, breathing frequency, peak inspiratory pressure [PIP], and PEEP during the 24 hours after thoracostomy); complications of thoracostomy (including empyema, surgical emphysema, and hemothorax); chest tube duration; time to readiness for weaning; time to disconnection from mechanical ventilation; weaning outcome; ICU mortality; and hospital mortality.

Definitions

The diagnosis of pneumothorax was based on the presence of an abnormal collection of air in the pleural space on an x-ray or CT, before or after chest tube placement. If invasive procedures (eg, thoracentesis, pericardiocentesis, central venous catheterization, pulmonary artery catheterization, or bronchoscopy) had been performed within 24 hours before a pneumothorax on the same side, the pneumothorax was considered procedure-related.¹⁵ It was considered a tension pneumothorax if there was an opposite mediastinal shift on x-ray and hemodynamic compromise.¹⁵ Surgical emphysema was defined as subcutaneous emphysema following chest tube placement.¹⁶ Empyema was defined as a pleural effusion culture that

revealed bacterial growth, or if gross pus was drained. Hemothorax was defined as bloody pleural effusion with a hematocrit level more than half of the hematocrit level in the blood. Chest tubes were removed when agreed upon by the surgeon and attending physician if lung expansion on chest x-ray and no leakage of air was observed in the underwater-sealed bottle for 2 days.¹⁷ Septic shock was defined as systemic inflammatory response syndrome (≥ 2 of the following conditions: temperature $> 38.5^{\circ}\text{C}$ or $< 35.0^{\circ}\text{C}$, heart rate > 90 beats/min, breathing frequency > 20 breaths/min or $P_{a\text{CO}_2} < 32$ mm Hg, and white blood cell count of $> 12,000$ cells/mL, $< 4,000$ cells/mL, or $> 10\%$ band forms) with shock (arterial systolic blood pressure < 90 mm Hg, or 40 mm Hg less than the subject's normal blood pressure) in response to documented infection.

Ready-for-weaning was defined as meeting the following criteria: recovery from an acute condition causing acute respiratory failure; $P_{a\text{O}_2}/F_{\text{IO}_2} > 200$ mm Hg; $\text{PEEP} \leq 8$ cm H_2O ; breathing frequency < 35 breaths/min; tidal volume > 5 mL/kg, minute ventilation < 10 L/min; stable hemodynamic status without inotropic agents or vasopressors; temperature $< 38^{\circ}\text{C}$; and adequate cough reflex and consciousness. Successful weaning from mechanical ventilation was defined as disconnection of invasive ventilation for at least 48 hours.

Statistical Analysis

We analyzed the differences between subjects with prolonged versus non-prolonged chest tube duration. Categorical data were compared using the chi-square test, and continuous variables were compared using the Student *t* test or Mann-Whitney U test when the distributions were either normal or not normal, respectively. We identified independent risk factors via multivariate logistic regression. Variables with a *P* value $< .20$ in the univariate analysis were considered for inclusion in the multivariate model. The multivariate model was also adjusted for confounding factors, including age, sex, smoking status, Acute Physiology and Chronic Health Evaluation II score, and $P_{a\text{O}_2}/F_{\text{IO}_2}$. We used receiver operating characteristic curve analysis to determine the optimal cutoff point that allowed the creation of dichotomous variables. The probability of chest tube removal was calculated with the Kaplan-Meier method and the log-rank test. Two-sided tests with a *P* value of $< .05$ were considered significant. Statistics software (SPSS 19, SPSS, Chicago, Illinois) was used for data analysis.

Results

Characteristics of the Study Subjects

One hundred six subjects had both pneumothorax and respiratory failure during the study period (Fig. 1). Eight

Fig. 1. Flow chart. Median chest tube duration was calculated from 52 pneumothorax episodes in 51 subjects who had successful chest tube removal.

patients were not eligible for inclusion, and 10 were excluded (5 received thoracostomy outside of our hospital,

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Table 1. Baseline Characteristics of the Study Subjects

	All Subjects <i>n</i> = 63*	Prolonged Chest Tube Duration <i>n</i> = 34	Non-prolonged Chest Tube Duration <i>n</i> = 29	<i>P</i>
Age, mean $\pm$ SD y	78.2 $\pm$ 12.3	76.7 $\pm$ 13.8	80.0 $\pm$ 10.3	.29
Male/female, no.	57/6	31/3	26/3	> .99
Smoker, no. (%)	36 (57.1)	23 (67.6)	13 (44.8)	.08
Comorbidities, no. (%)				
COPD	41 (65.1)	23 (67.6)	18 (62.1)	.79
Interstitial lung disease	2 (3.2)	2 (5.9)	0 (0)	.49
Heart failure	16 (25.4)	11 (32.4)	5 (17.2)	.24
Diabetes mellitus	15 (23.8)	9 (26.5)	6 (20.7)	.76
End-stage renal disease	2 (3.2)	1 (2.9)	1 (3.4)	> .99
Neurological disease	29 (46.0)	14 (41.2)	15 (51.7)	.45
Malignancy	10 (15.9)	7 (20.6)	3 (10.3)	.31
Reason for mechanical ventilation				
COPD	29 (46.0)	16 (47.1)	13 (44.8)	> .99
Post-surgical	2 (3.2)	0 (0)	2 (6.9)	.20
Pneumonia	24 (38.1)	12 (35.3)	12 (41.4)	.79
Pulmonary edema	2 (3.2)	2 (5.9)	0 (0)	.49
ARDS	1 (1.6)	1 (2.9)	0 (0)	> .99
Airway protection	3 (4.8)	2 (5.9)	1 (3.4)	> .99
Other†	2 (3.2)	1 (2.9)	1 (3.4)	> .99
On ICU admission				
APACHE II score, mean $\pm$ SD	18.7 $\pm$ 6.1	19.3 $\pm$ 6.7	18.1 $\pm$ 5.4	.45
P _{aO₂} /F _I O ₂ , mean $\pm$ SD mm Hg	292.5 $\pm$ 136.9	288.7 $\pm$ 149.6	297.1 $\pm$ 123.0	.81
Oxygenation index, mean $\pm$ SD‡	4.4 $\pm$ 3.3	4.6 $\pm$ 4.1	4.2 $\pm$ 2.4	.48

* 63 episodes in 61 subjects.

† One subject had asthma, and the other had obesity hypoventilation.

‡ No data obtained for 7 subjects, so prolonged *n* = 29 and non-prolonged *n* = 27.

APACHE = Acute Physiology and Chronic Health Evaluation

Table 2. Outcomes of the Study Subjects With and Without a Prolonged Chest Tube Duration

	All Subjects <i>n</i> = 63*	Prolonged Chest Tube Duration <i>n</i> = 34	Non-prolonged Chest Tube Duration <i>n</i> = 29	<i>P</i>
Chest tube duration, d	27.8 $\pm$ 24.6	41.7 $\pm$ 26.0	11.6 $\pm$ 5.7	.001
Duration of mechanical ventilation, d	47.1 $\pm$ 41.0	53.5 $\pm$ 37.0	39.5 $\pm$ 44.7	.17
From mechanical ventilation to pneumothorax, d	21.0 $\pm$ 33.2	18.1 $\pm$ 19.0	24.3 $\pm$ 44.6	.46
Ready for weaning, no. (%)	52 (82.5)	27 (79.4)	25 (86.2)	.52
From pneumothorax to ready for weaning (<i>n</i> = 52), d	6.9 $\pm$ 7.0	8.6 $\pm$ 8.1	5.2 $\pm$ 5.1	.07
From pneumothorax to disconnection of mechanical ventilation, d	26.1 $\pm$ 27.2	35.4 $\pm$ 32.3	15.2 $\pm$ 13.5	.003
Successful weaning, no. (%)	30 (47.6)	14 (41.2)	16 (55.2)	.31
ICU stay, d	35.9 $\pm$ 18.8	41.3 $\pm$ 17.7	29.6 $\pm$ 18.3	.01
From ICU admission to pneumothorax, d	8.3 $\pm$ 15.0	7.3 $\pm$ 14.3	9.4 $\pm$ 16.1	.59
From pneumothorax to discharge, d	27.6 $\pm$ 15.9	34.0 $\pm$ 17.7	20.2 $\pm$ 9.1	.001
Hospital stay, d	85.9 $\pm$ 118.6	95.5 $\pm$ 99.3	74.6 $\pm$ 138.8	.01
From admission to pneumothorax, d	36.1 $\pm$ 106.2	32.8 $\pm$ 83.0	40.0 $\pm$ 129.7	> .99
From pneumothorax to discharge, d	49.8 $\pm$ 38.4	62.7 $\pm$ 44.8	34.6 $\pm$ 21.7	.004
ICU mortality, no. (%)	15 (23.8)	13 (38.2)	2 (6.9)	.006
Hospital mortality, no. (%)	24 (38.1)	17 (50)	7 (24.1)	.04

* 63 episodes in 61 subjects.

$\pm$ Values are mean $\pm$ SD.

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Table 3. Manifestations and Management of Pneumothorax Among Subjects With and Without Prolonged Chest Tube Duration

	All Subjects <i>n</i> = 63*	Prolonged Chest Tube Duration <i>n</i> = 34	Non-prolonged Chest Tube Duration <i>n</i> = 29	<i>P</i>
Bilateral pneumothorax, no. (%)	5 (7.9)	4 (11.8)	1 (3.4)	.36
Procedure-related pneumothorax, no. (%)	19 (30.2)	10 (29.4)	9 (31.0)	> .99
Tension pneumothorax, no. (%)	4 (6.3)	3 (8.8)	1 (3.4)	.61
Concurrent septic shock, no. (%)	5 (7.9)	3 (8.8)	2 (6.9)	> .99
Thoracotomy, no. (%)	2 (3.2)	2 (5.9)	0 (0)	.49
Chest CT, no. (%)	34 (54.0)	23 (67.6)	11 (37.9)	.02
Number of CTs, mean ± SD	0.8 ± 1.0	1.2 ± 1.2	0.4 ± 0.6	.003
Number of chest tubes, mean ± SD	1.4 ± 0.7	1.7 ± 0.8	1.2 ± 0.5	.005
Mechanical ventilation settings within 24 h of thoracostomy (<i>n</i> = 56), mean ± SD				
Maximum PEEP, cm H ₂ O	2.9 ± 2.7	2.8 ± 2.9	2.9 ± 2.5	.78
Maximum PIP, cm H ₂ O	25.8 ± 6.0	27.6 ± 6.2	24.0 ± 5.2	.03
Maximum $\dot{V}_E$, L/min	11.2 ± 3.3	11.9 ± 4.1	10.4 ± 2.2	.13
Maximum $\dot{V}_T$, mL	616.5 ± 133.3	612.1 ± 131.2	621.2 ± 138.2	.90
Maximum breathing frequency, breaths/min	20.1 ± 7.3	21.8 ± 9.0	18.3 ± 4.5	.08
Complications				
Surgical emphysema, no. (%)	38 (60.3)	26 (76.5)	12 (41.4)	.009
Time to surgical emphysema, mean ± SD d	1.2 ± 3.0	1.5 ± 3.5	0.5 ± 0.8	.66
Empyema, no. (%)	21 (33.3)	17 (50)	4 (13.8)	.002
Time to empyema, mean ± SD d	13.0 ± 13.0	14.3 ± 13.2	7.5 ± 11.9	.38
Empyema before prolonged chest tube duration, no. (%)	13 (20.6)	10 (29.4)	3 (10.3)	.11
Empyema after prolonged chest tube duration, no. (%)	8 (12.7)	7 (20.6)	1 (3.4)	.06
Hemothorax, no. (%)	0 (0)	0 (0)	0 (0)	

* 63 episodes in 61 subjects
CT = computed tomography
PIP = peak inspiratory pressure
 $\dot{V}_E$ = minute ventilation
 $\dot{V}_T$ = tidal volume

one had empyema before pneumothorax, and 4 were transferred from the ICU to an ordinary ward against the advice of the attending physician). Among the 88 subjects enrolled, 51 subjects (57.9%) with 52 episodes of pneumothorax successfully had their chest tubes removed, and the median chest tube duration was 18 days (range 2–88 d). Twenty-seven subjects who died with chest tubes before the median chest tube duration (18 d) were excluded. Thus, in total, 61 subjects and 63 episodes of pneumothorax were analyzed and divided into a prolonged chest tube duration group (> 18 d) and a non-prolonged group (≤ 18 d). There were 34 subjects with 34 events in the prolonged chest tube duration group, and 29 subjects with 29 events in the non-prolonged group. The baseline characteristics of the study subjects are shown in Table 1, and there were no significant differences between the 2 groups.

Impact of Prolonged Chest Tube Duration on Outcomes

The outcomes of the study subjects are shown in Table 2. The subjects with prolonged chest tube duration had longer ICU stay (34.0 ± 17.7 d vs 20.2 ± 9.1 d, $P = .001$), hospital stay (62.7 ± 44.8 d vs 34.6 ± 21.7 d, $P = .004$), and mechanical ventilation after development of pneumothorax (35.4 ± 32.3 d vs 15.2 ± 13.5 d, $P = .003$), and higher ICU mortality (38.2% vs 6.9%, $P = .006$) and hospital mortality (50.0% vs 24.1%, $P = .04$).

Factors Associated With Prolonged Chest Tube Duration

The initial manifestations of pneumothorax in the study subjects are shown in Table 3. Prolonged chest tube duration was significantly associated with a higher rate of

Table 4. Logistic Regression Analysis of Factors Associated With Prolonged Chest Tube Duration

	Univariate Odds Ratio (95% CI)	<i>P</i>	Multivariate Adjusted Odds Ratio (95% CI)	<i>P</i>
Age	0.98 (0.93–1.02)	.31	0.92 (0.83–1.01)	.08
Sex	1.19 (0.22–6.42)	.84	2.33 (0.09–57.79)	.60
Smoking	2.57 (0.92–7.18)	.07	1.06 (0.21–5.41)	.94
Acute Physiology and Chronic Health Evaluation II score	1.03 (0.95–1.12)	.45	1.07 (0.94–1.21)	.31
P _{aO₂} /F _{IO₂}	1.00 (1.00–1.00)	.81	0.99 (1.00–1.01)	.86
Procedure-related pneumothorax	1.08 (0.37–3.18)	.89		
Bilateral pneumothorax	3.73 (0.39–35.46)	.25		
Concurrent septic shock	1.31 (0.20–8.41)	.78		
Tension pneumothorax	2.71 (0.27–27.58)	.40		
Maximum minute ventilation	1.15 (0.97–1.37)	.11	0.98 (0.66–1.44)	.90
Maximum tidal volume	1.00 (0.99–1.00)	.86		
Maximum PEEP	1.04 (0.85–1.26)	.72		
Maximum breathing frequency	1.08 (0.98–1.18)	.11	1.13 (0.92–1.38)	.25
Maximum peak inspiratory pressure	1.13 (1.02–1.26)	.03	1.18 (1.01–1.37)	.03
Surgical emphysema before prolonged chest tube duration (<i>n</i> = 38)	4.60 (1.56–113.61)	.006	11.18 (2.03–61.51)	.006
Empyema before prolonged chest tube duration (<i>n</i> = 13)	3.61 (0.89–14.71)	.07	2.54 (0.33–19.70)	.37

CT (67.6% vs 37.9%, $P = .02$), a higher number of CTs (1.2 ± 1.2 vs 0.4 ± 0.6 , $P = .003$), a higher number of chest tubes (1.7 ± 0.8 vs 1.2 ± 0.5 , $P = .005$), a higher maximum PIP (27.6 ± 6.2 cm H₂O vs 24.0 ± 5.2 cm H₂O, $P = .03$), a higher rate of surgical emphysema (76.5% vs 41.4%, $P = .009$), and a trend toward more empyema after prolonged chest tube duration (20.6% vs 3.4%, $P = .06$). Additionally, in subjects with chest CT, subjects in the prolonged group (9 of 23 subjects, 39.1%) had a trend toward a higher rate of chest tube malposition ($P = .07$) than did the non-prolonged group (1 of 11 subjects, 9.1%).

Independent Risk Factors Associated With Prolonged Chest Tube Duration

In the multivariate logistic regression analysis the significant predictors of prolonged chest tube duration were maximum PIP within 24 hours after insertion of chest tube (odds ratio 1.178, 95% CI 1.014–1.370, $P = .03$) and surgical emphysema (odds ratio 11.182, 95% CI 2.033–61.514, $P = .006$) (Table 4). The receiver operating characteristic curve analysis revealed that the optimal cutoff point to create dichotomous variables for maximum PIP was 25 cm H₂O (sensitivity 0.72, specificity 0.63, area under the curve 0.70). Kaplan-Meier analysis of the rate of chest tube removal within 28 days after chest tube insertion (Fig. 2) indicated that the probability of chest tube removal was significantly lower and removal of the chest tube was also delayed when both surgical emphysema and a high PIP were present, compared with subjects without surgical emphysema or a high PIP (log-rank $P = .001$).

Fig. 2. Kaplan-Meier curve for chest tube duration in subjects who developed pneumothorax after initiation of mechanical ventilation. We divided the subjects into 4 groups, according to the presence/absence of surgical emphysema, and peak inspiratory pressure (PIP) > 25 cm H₂O versus ≤ 25 cm H₂O. The lowest percentage of chest tube removal within 28 days after thoracostomy was in the group with surgical emphysema and high PIP (log rank $P = .001$, compared with no surgical emphysema and low PIP).

Discussion

The importance of avoiding prolonged chest tube duration has been identified with other pleural diseases.¹⁸ However, little attention has been paid to chest tube duration in patients on mechanical ventilation,^{16,17,19} in whom management is more complicated¹⁷ and the impact of prolonged chest tube duration is unknown.

Our subjects had an average age of 78 years, and various comorbidities, especially COPD. We found that prolonged chest tube duration after pneumothorax was associated with higher mortality, longer ICU and hospital stay, and longer mechanical ventilation after pneumothorax. The prolonged chest tube duration subjects also tended to receive more chest CTs, have more chest tubes, and have a higher rate of empyema. These findings indicate that the burden of critical care is increased in subjects with pneumothorax and prolonged chest tube duration. This seems an inviting topic to explore to shorten the period of thoracostomy.

Notably, in this retrospective study, we also found an association between prolonged chest tube duration and thoracostomy complications. Thoracostomy complications have a relatively high incidence (~25–30%^{8,9}) and may worsen outcomes.^{3–9} Subcutaneous emphysema is usually thought to be only a cosmetic issue.^{16,20} Jones et al enrolled 134 subjects, and 17 (12.6%) of them were mechanically ventilated. Subjects with subcutaneous emphysema after thoracostomy (so-called surgical emphysema) had a higher mortality rate, longer chest tube duration, and a higher incidence of chest tube malposition.⁶ However, in that study, a much higher percentage of subjects with surgical emphysema were mechanically ventilated, which may have biased the results. In our subjects, surgical emphysema was significantly associated with prolonged chest tube duration in subjects who developed pneumothorax during ventilation. That observation reinforces the viewpoint that surgical emphysema in mechanically ventilated patients is associated with prolonged chest tubes duration and may reflect inadequate functioning of the chest tube or chest tube malpositioning.

Interestingly, 34 of our subjects (55.7%) received chest CT to evaluate pneumothorax. On average, they received their first CT at about 10.5 days after thoracostomy. We hypothesize that this may be too late to evaluate chest tube malfunctioning and pneumothorax-associated complications. Subjects with prolonged chest tube duration have a trend toward a higher rate of chest tube malposition, so we suggest early chest CT to avoid prolonged chest tube duration. We suggest CT instead of x-ray, because x-ray is less accurate for assessing pneumothorax or chest tube malpositioning.^{21–24}

In our results, prolonged chest tube duration was also associated with higher PIP. Positive pressure from a ventilator is believed to delay healing of pneumothorax,¹⁷ and a higher inspiratory pressure may worsen persistent air leak. However, the influence of ventilator settings on the resolution of pneumothorax and chest tube duration has not been investigated. We found that prolonged chest tube duration was significantly associated with a higher maximum PIP within 24 hours of thoracostomy. Fur-

thermore, when we evaluated the impact of surgical emphysema and high PIP (> 25 cm H₂O) on chest tube removal, it was found that the rate of chest tube removal in subjects with both adverse factors was half that of subjects without either factor on day 28 after chest tube insertion (see Fig. 2).

Our study has some limitations. First, this was a retrospective study, and the ventilator setting records were not available for 7 subjects. Second, we focused on subjects who developed pneumothorax during mechanical ventilation. Whether our findings can be generalized to patients who develop pneumothorax without mechanical ventilation remains unknown. Third, our subjects were mainly elderly and had a high rate of COPD. The generalization of our findings to patient populations with other characteristics warrants further investigation. Fourth, because of the limitations of a retrospective study, there could be confounding factors we did not account for.

Conclusions

Prolonged chest tube duration was associated with a higher mortality, a longer duration of mechanical ventilation after development of pneumothorax, and longer ICU and hospital stay. Surgical emphysema and high PIP within 24 hours after thoracostomy were independent predictors of prolonged chest tube duration.

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