Spontaneous Recovery of Ventilator-Associated Pneumothorax

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Abstract

Background: The usual management of ventilator-associated pneumothorax (VPX) is tube thoracostomy. However, this recommendation is based on tradition rather than on solid evidence. Although it has been applied successfully to other types of pneumothoraces, observation has not been used in the management of VPX. Objectives: In this study, we investigated whether observation is a valid treatment strategy for VPX. Methods: We retrospectively analyzed data of 471 patients with VPX (2003–2010) and found that 27 did not receive tube thoracostomy. Most of those patients (89%) had documented do-not-resuscitate orders and had refused tube thoracostomy. For comparison, 54 patients with tube thoracostomy, matched by age and do-not-resuscitate status, were chosen as controls. Among patients without tube thoracostomy, we compared attribute differences between those recovered and those not recovered. Results: Thirteen patients (48%) without tube thoracostomy experienced spontaneous recovery of their pneumothoraces. This rate of chest tube-free recovery was higher than that of patients with tube thoracostomy (48 vs. 17%; p = 0.003). The patients did not differ in in-hospital mortality rate, time to ventilator discontinuation or survival. By univariate logistic regression, spontaneous recovery was associated with VPX caused by needle puncture, lack of respiratory distress, large tidal volume and low oxygen requirement following pneumothorax, as well as by physician recommendation against intubation. Conclusion: Observation under physician surveillance is an effective option of managing many VPXs, especially those caused by needle puncture, when patients are not in respiratory distress or when patients have acceptable tidal volumes and oxygen requirements following pneumothorax.

Key Words
Chest tubes • Mechanical ventilators • Pneumothorax

Introduction

Ventilator-associated pneumothorax (VPX) is among the leading causes of iatrogenic pneumothorax [1, 2], with 3–8% of mechanically ventilated patients developing pneumothorax or other forms of barotrauma [3–5]. VPX is the second most common cause of acute hypoxia occurring during ventilator support [6]. In 1974, in a retrospective observational study, Steier et al. [7] report-
ed that 71 of 74 (95%) VPX patients had tension components. They also reported a mortality rate of 31% if chest tube insertion was delayed for 30 min to 8 h while awaiting chest X-ray (CXR) confirmation. In contrast, mortality was only 7% if the chest tube was inserted immediately, based on clinical suspicion. They concluded that a pneumothorax in a mechanically ventilated patient was an ‘acute surgical emergency which demands immediate decompression’. The argument successfully convinced medical providers, and this approach has seldom been challenged [8]. Tube thoracostomy is the current standard treatment of VPX, being explained this way in nearly every medical textbook [9–11].

We question whether the suggestion derived from the study of Steier et al. [7] over 3 decades ago is still applicable to current VPX patients. First, according to the tenets of evidence-based practice, results of a single retrospective observational study do not provide strong evidence or allow for a high level of recommendation [12]. Second, the 95% reported rate of conversion to tension pneumothorax seems to be an overestimate. The ventilator settings reported by Steier et al. [7] are very unusual in contemporary respiratory care. For example, the mean tidal volumes of patients with pneumothorax were 18 ml/kg (range 14–21), which are extraordinarily high compared to current guidelines (6–12 ml/kg) [13]. Today, smaller volumes (4–6 ml/kg) are widely used in a lung-protective strategy [14]. Their reported mean end-inspiratory pressure was 46 cm H₂O (range 38–55), which is also higher than the current practice (<30 cm H₂O) [15]. We suspected that the unusually large tidal volumes and high airway pressures, now rarely used, contributed to the high incidence of tension pneumothorax reported by Steier et al. [16, 17]. Our assumptions are supported by a later survey (but prior to the lung protective strategy era) showing that only about 30% of VPX patients had tension components [18]. Third, expectant management of VPX (without chest tube insertion) has been successfully practiced for selected pediatric patients for about a decade [19, 20]. One recent retrospective observation revealed that 77% of neonatal VPX treated by expectant management resolved without chest tube insertion [20]. Fourth, there has been an increased awareness of complications associated with chest tube insertion [21–23]. Therefore, we believe that it is time to reconsider whether tube thoracostomy is warranted for all patients with VPX. The observation strategy has been used successfully for many spontaneous [24], iatrogenic [11] and traumatic pneumothoraces [25]. We hypothesized that observation may also be an effective management for some VPXs. In this study, we retrospectively evaluated medical records for VPX patients treated by observation strategy in our hospital.

**Material and Methods**

We retrospectively searched the discharge files of patients admitted to Changhua Christian Hospital, a 1,670-bed medical center in central Taiwan. Totally, 471 VPX patients were found from December 2003 to April 2010. Among those, 27 did not receive any chest tube or pigtail catheter insertion; 89% of those 27 had do-not-resuscitate (DNR) orders. The control group was randomly selected from the same database and consisted of 54 age- and DNR status-matched patients with tube thoracostomy.

The medical charts and serial CXR films for each enrolled patient were carefully reviewed by two experienced pulmonologists (S.-H.W. and M.-H.H.). In the case of a conflict of opinions, a third pulmonologist (K.-H.L.) made the final judgment. Data analyzed included demographic information, underlying diseases, CXR features, ventilator settings and vital signs before and shortly following pneumothorax. The target outcomes included: number of chest tube-free pneumothorax recovery, time to chest tube-free recovery, number of pneumothorax disappearance on CXR, time to pneumothorax disappearance on CXR, in-hospital mortality, time to ventilator discontinuation, evolution of tension components, and survival time.

The severity of disease was estimated by the Sequential Organ Failure Assessment score [26]. The pneumothorax size was calculated by the following equation: \[1 – \left(\text{diameter of lung/diameter of hemithorax}^{\frac{3}{2}}\right) \times 100\%\], also known as Light index [27]. Tension pneumothorax was determined by the presence of mediastinal shifting or diaphragm depression on CXR [7, 28]. Chest tube-free pneumothorax recovery was defined by both disappearance of the pneumothorax on CXR and by no tube draining of the pleural space. The addition of chest tube removal to the definition was to exclude VPXs associated with persistent air bubbling through the chest tube and underwater seal when their CXR seemed recovered. For those experiencing spontaneous recovery of VPX, the rate of absorption of the pneumothorax was estimated by dividing the size of the pneumothorax (in %) by the time interval (in days) between pneumothorax occurrence and resolution. The study was approved by the Institutional Review Board of Changhua Christian Hospital.

**Statistical Analysis**

We used the Mann-Whitney U test to compare continuous variables. When comparing two categorical variables, the \(\chi^2\) or Fisher’s exact test was used. In Kaplan-Meier survival rate analysis, the log-rank test was used to calculate the difference. Logistic regressions with univariate and multivariate analysis were applied for detecting factors predisposing to spontaneous recovery. Variables included in the multivariate analysis were factors with significant difference by univariate analysis. A p value <0.05 was considered statistically significant. All statistical analyses were performed using SPSS 15.0 software (Chicago, Ill., USA).
Results

Baseline Characteristics of VPX Patients
The baseline characteristics of VPX patients with or without tube thoracostomy are listed in table 1. Patients did not differ in age or sex. Their underlying illnesses were similar except for more sepsis (93 vs. 65%; p = 0.007) and higher Sequential Organ Failure Assessment scores (8 vs. 7; p = 0.04) in the ‘without tube’ group. Although the ‘with tube’ group had a smaller fraction of inspiratory oxygen content at the time of pneumothorax diagnosis (40 vs. 60%; p = 0.03), the groups had similar oxygen requirements shortly after pneumothorax was found (70 vs. 60%; p = 0.84).

Outcome Comparisons between VPX Patients with and without Tube Thoracostomy
The outcome comparisons between VPX patients with and without tube thoracostomy are shown in table 2. Of 27 VPX patients without tube thoracostomy, 13 (48%) experienced spontaneous recovery of their pneumothoraces (fig. 1, 2). This rate of chest tube-free recovery was higher...
than that of patients treated by tube thoracostomy (48 vs. 17%; p = 0.003). Both groups required a similar time to achieve chest tube-free recovery (4.0 vs. 9.0 days; p = 0.06). Both groups had similar rates of pneumothorax resolution on CXR (48 vs. 65%; p = 0.15), but it took more time for the observation group to attain roentgenological recovery (4.0 vs. 1.0 day; p = 0.04). Patient groups did not differ in in-hospital mortality rate, time to ventilator discontinuation, evolution of tension component or survival probability (fig. 3). For VPX treated by observation strategy, the estimated median rate of re-absorption of the pneumothorax was 6.4% (interquartile range 3.2–13.2) per day.
Factors Predisposing to Spontaneous Recovery in VPX Patients without Tube Thoracostomy

Possible factors predisposing to spontaneous recovery are selectively displayed in Table 3. By univariate analysis, we found that VPX caused by needle puncture [odds ratio (OR) 30.00, p = 0.03], not associated with respiratory distress (OR 8.25, p = 0.02), having larger tidal volumes (OR 1.01 for every milliliter increase, p = 0.03) and having lower oxygen requirements (OR 0.97 for every % decrease, p = 0.03) after pneumothorax, and physician recommendation against intubation (OR 9.95, p = 0.02) were all associated with a higher chance of spontaneous recovery.

Table 3. Factors predisposing to spontaneous recovery in VPX without tube thoracostomy

<table>
<thead>
<tr>
<th></th>
<th>No recovery (n = 14)</th>
<th>Spontaneous recovery (n = 13)</th>
<th>Univariate analysis</th>
<th>Multivariate analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>OR</td>
<td>OR</td>
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<tr>
<td>Cause of pneumothorax</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiopulmonary resuscitation</td>
<td>6 (43%)</td>
<td>1 (8%)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Needle puncture</td>
<td>1 (7%)</td>
<td>5 (39%)</td>
<td>30.0 [1.47–611.8]</td>
<td>0.03</td>
</tr>
<tr>
<td>Unknown</td>
<td>7 (50%)</td>
<td>7 (54%)</td>
<td>6.00 [0.57–63.68]</td>
<td>0.14</td>
</tr>
<tr>
<td>Ventilator parameters after pneumothorax</td>
<td></td>
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<tr>
<td>Tidal volume, ml</td>
<td>416 (313–568)</td>
<td>629 (468–715)</td>
<td>1.01 [1.00–1.01]</td>
<td>0.03</td>
</tr>
<tr>
<td>Fraction of inspiratory oxygen content, %</td>
<td>100 (70–100)</td>
<td>50 (35–85)</td>
<td>0.97 [0.94–1.00]</td>
<td>0.03</td>
</tr>
<tr>
<td>Mean airway pressure, cm H2O</td>
<td>12 (10–20)</td>
<td>9 (6–15)</td>
<td>0.81 [0.65–1.02]</td>
<td>0.10</td>
</tr>
<tr>
<td>Positive end-expiratory pressure, cm H2O</td>
<td>0 (0–4)</td>
<td>0 (0–5)</td>
<td>1.02 [0.77–1.36]</td>
<td>0.87</td>
</tr>
<tr>
<td>Location of pneumothorax (right)</td>
<td>4 (29%)</td>
<td>6 (46%)</td>
<td>2.14 [0.44–10.53]</td>
<td>0.35</td>
</tr>
<tr>
<td>Size of pneumothorax, %</td>
<td>46 (27–66)</td>
<td>34 (19–52)</td>
<td>0.97 [0.93–1.01]</td>
<td>0.19</td>
</tr>
<tr>
<td>Initial tension component</td>
<td>6 (43%)</td>
<td>6 (46%)</td>
<td>1.14 [0.25–5.22]</td>
<td>0.86</td>
</tr>
<tr>
<td>Reason for no tube thoracostomy</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Family’s refusal</td>
<td>10 (71%)</td>
<td>9 (69%)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Physician judgment</td>
<td>0 (0%)</td>
<td>4 (31%)</td>
<td>9.95</td>
<td>0.02</td>
</tr>
<tr>
<td>Too urgent to insert</td>
<td>4 (29%)</td>
<td>0 (0%)</td>
<td>–</td>
<td>0.13</td>
</tr>
<tr>
<td>No respiratory distress</td>
<td>3 (21%)</td>
<td>9 (69%)</td>
<td>8.25 [1.45–46.86]</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Data are medians with interquartile ranges in parentheses, or number of cases with percentages, unless otherwise indicated. Figures in brackets are 95% confidence intervals.

Fig. 2. A 76-year-old male with right-sided VPX. a The pneumothorax manifesting a mediastinal shift to the contralateral side. The patient’s family refused tube thoracostomy. b Sixteen days later, the size of the pneumothorax had decreased on CXR. c There was no evidence of pneumothorax on the CXR film taken 24 days after the pneumothorax. The patient remained ventilator dependent but pneumothorax free. He died of multi-organ failure 8 months later.
taneous recovery. No single variable independently affected the likelihood of spontaneous recovery in multivariate analysis.

Discussion

In this study, we demonstrated for the first time that observation under physician surveillance was an effective treatment option for many VPXs. When applied to appropriate patients, this conservative management may reduce unnecessary patient suffering and costs associated with tube thoracostomy.

The current recommendation to perform tube thoracostomy for all VPX patients is based on a study with a high reported incidence of conversion to tension pneumothorax [7]. However, our study found that the tension component occurred in only about 40% of patients initially, and that the number decreased over time. Diagnosis of tension pneumothorax by mediastinal shifting on CXR, as applied by Steier et al. [7] and us, may be inaccurate or misleading [29]. Such a mediastinal displacement may occur due to natural recoil of the chest wall and lung when air enters the pleural space, without a true tension in the pleural space [11]. Our results showed that patients with and without these roentegenological signs had similar chances of spontaneous recovery. Thus, the decision to proceed with tube thoracostomy should not rely solely on radiographic presentation.

When pleural defects seal, the retained air in the pleural space will eventually be absorbed into pleural capillaries. The rate of pleural gas absorption was estimated to be 2.2% of the volume of the hemithorax every 24 h in spontaneous pneumothorax [30]. We found the re-expansion rate of VPX was about 6.4% daily. This quicker rate of re-expansion may be explained in part by the fact that most VPX patients in our study received supplemental oxygen, which has been shown to be helpful in hastening absorption of air in the pleural cavity [31].

Surprisingly, we found that VPX patients who managed without tube thoracostomy showed a greater chance of chest tube-free recovery than those with a tube. Although a chest tube can rapidly evacuate intrapleural air on CXR films, the tubes of most patients (83%) could not be removed before their deaths due to persistent air leakage. Perhaps the chest tubes relieved the intra-pleural pressure and widened the pressure gradient between the airway and pleural space. Consequently, airflow through the bronchopleural fistula [32] increased and healing of the pleural defect was prolonged. We think this mechanism was especially important in patients receiving positive pressure ventilation; it likely led to protracted chest tube use.

In spontaneous pneumothorax, the size of the pneumothorax is less important than clinical breathlessness in determining a management strategy [33]. Our data showed that patients who experienced spontaneous recovery had smaller VPXs compared to those who did not recover spontaneously, but the difference was not significant. And the size of the pneumothorax did not correlate well with clinical manifestations [34]. One explanation for this discrepancy is that calculation of the size of the 3-dimensional lung structure by 2-dimensional imaging is imprecise. As with spontaneous pneumothorax [33] and some traumatic pneumothoraces [25], ‘no breathlessness’ was an important predictor of spontaneous recovery. VPXs caused by needle puncture had a greater chance of spontaneous recovery compared to those caused by cardiopulmonary resuscitation. Unlike a pneumothorax caused by bursting of pleural defects like bullae or blebs [35], needle puncture usually occurs at random location with little chance of coinciding with a preexisting pleural defect. We believe this to be the reason why these patients recover more rapidly. Other predictors were larger tidal volume and lower oxygen requirement after pneumotho-
Another interesting observation is that all 4 VPX patients not receiving tube thoracostomy because of physician recommendation recovered spontaneously. We believe that these physicians considered the above variables before making their decisions. Because all patients were under surveillance at the hospital, physicians knew that emergent measures, such as chest intubation, could be taken if needed. Although none of the above factors independently influenced the outcome in our multivariate analysis, they provide a clinical picture when viewed together.

Our study was limited by its retrospective, non-randomized design. Because tube thoracostomy is currently the mainstay of treatment, conducting a prospective clinical trial against this policy is unethical at this time. With accumulating evidence, a randomized clinical trial may become more acceptable in the future. (Proposed inclusion criteria for such a trial are VPX patients admitted in a ward capable of intensive monitoring, >18 years old, without respiratory distress or hemodynamic instability, with a fraction of inspired oxygen <50% and a positive end-expiratory pressure <10 cm H₂O. Patients with their VPXs detected shortly after a cardiopulmonary resuscitation should be excluded.) Because non-intubated VPX patients were very rare, the study was also hindered by small case numbers. Most patients did not receive daily CXRs, so VPX changes were not precisely chronicled, and therefore, all the reported time courses and intervals were subject to imprecision. The generalizability of this study is limited by its unique patient population, which included 89% DNR patients. These patients experienced incurable illnesses or grave financial situations. We expect an even higher chance of spontaneous recovery and survival if this study were conducted among a healthier patient cohort.

In conclusion, observation under physician surveillance is an effective management strategy for many VPXs, especially those caused by needle puncture, not associated with respiratory distress and having acceptable tidal volume and oxygen requirements after the pneumothorax.

Acknowledgments

The authors thank Ms. Yu-Jun Chang of the Epidemiology and Biostatistics Center of Changhua Christian Hospital for the statistical analysis. We are also obliged to Ms. Hui-Chi Hsieh, Pei-Ying Wang, Siao-Hua Liou, Li-Chin Su, Chia-Li Kao, Hsing-Fang Wu and Hwei-Jyun Chen for their secretarial assistance. We thank Dr. Lon-Yen Tsao for the critical review of the manuscript.

References


