Root Cause of Analysis of Peculiar Response of Pneumothorax to Chest Tube Drainage

Szeto Ching Ho

Department of Tuberculosis and Chest, Wong Tai Sin Hospital, Hong Kong, China

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Abstract Chest tube drainage is a simple system to manage pneumothorax. It is inserted at the safety triangle after local anesthesia. Due to the positive intrapulmonary pressure and the negative intrapleural pressure during inspiration, air in the pleural space will be forced out into the chest drain bottle with underwater seal. The resorption of pneumothorax is further enhanced by oxygen therapy, which displaces the nitrogen inside the pneumothorax. Out of our expectation, there are cases with peculiar response to chest tube drainage. We should consider the following in the root cause analysis. **1. Chest drain system integrity:** The chest drain should be placed in the pleural cavity, rather than sub-cutaneous or intra-abdominal cavity. The tubing should not be kinked or disconnected and the connection site should not be masked by dressing. **2. Anatomy of the pneumothorax:** The anatomy of the pneumothorax should be on CXR or preferably contrast CT thorax. Any loculation, endobronchial obstruction, trapped lung due to old inflammatory process, lung entrapment due to persistent active inflammatory process should be noted. **3. Clinical assessment:** It includes pleural fluid analysis, if present, and pleural manometry with air aspiration. In case of persistent air-leak seen in the chest drain bottle, suspect alveolopleural or bronchopleural fistula especially when patient is on positive pressure ventilation. Alternating or persistent bilateral pneumothorax without air-leak suggests interpleural communication (Simultaneous Bilateral Spontaneous Pneumothorax). The observed phenomena can be explained by considering the pressure change between various intra-thoracic compartments accounts for the observed phenomena, although confirmation of the communication during thoracoscopy is preferred.

Keywords Root Cause Analysis (RCA), Unresolved Pneumothorax, Chest Drain, Loculated Pneumothorax, Trapped Lung, Lung Entrapment, Simultaneous Bilateral Spontaneous Pneumothorax (SBSP), Alveolo-pleural and Broncho-pleural Fistula

1. Introduction

Root cause analysis can solve the problem of unresolved pneumothorax despite chest tube drainage. Removal of the root cause from the sequence of events prevents the final undesirable effect from recurring¹.

2. Materials and Methods

During the period Jan 1, 2011 to July 31, 2015, 14450 episodes of pneumothorax were reported across hospitals in Hong Kong as recorded in the Clinical Data Analysis and Reporting System (CDARS) using ICD-9 coding. The data comes from 42 public hospitals and institutions, 47 specialist outpatient clinics and 73 general outpatient clinics. These are organised into 7 hospital clusters based on location. Although the CDARS system is powerful, the incorrect disease entry by individual doctor may make the interpretation difficult. Having said that, we can observe the general trend of disease prevalence and the treatment received. For example, simple pneumothorax will be treated by observation with oxygen therapy. Some cases are treated with chest drain only. More difficult cases may require talc pleurodesis to prevent recurrence. Patients on mechanical ventilation or requiring surgical thoracoscopy reflect the portion of 'difficult pneumothorax'. By investigating each step from the chest drain insertion, daily monitoring, application of suction, pleurodesis, up to the removal of chest drain, we can identify the root cause of 'difficult pneumothorax'.

3. Results

Out of the 14450 patients with pneumothorax, 5554 (38.4% of total) patients required chest drain insertion. Most patients (91% of total) suffered from spontaneous pneumothorax and only 3.3% of total patients had spontaneous tension pneumothorax. 5.8% patients acquired

pneumothorax during medical procedure. 1418 patients (9.8% of total) required surgical intervention and pleurodesis.

1185 patients (8.2% of total) with pneumothorax were put on positive pressure mechanical ventilation for one reason or the other. They were prone to develop bronchopleural fistula. Some patients with 'difficult pneumothorax' have poor general condition and cannot tolerate the general anaesthesia and surgical intervention. Although this portion of patients is small, treatment is still available.

39 patients (0.27%) with empyema thoracis developed fistula leading to hydropneumothorax. There were 581 cases of tuberculous pleural effusion (23 cases has lung cavity) requiring chest tube drainage but, interestingly, there was no documented tuberculous pneumothorax in the past 4.5 years.

Ultrasound thorax (135 patients, 0.93%) was less commonly used in pneumothorax as compared to CT thorax (825 patients, 5.7%) due to the inferior sensitivity in detecting small pneumothorax, and 'relatively' less information obtained.

Patients with pneumothorax and trapped lung (13 patients, 0.09%) were much less common than those with pneumothorax and lung entrapment (406 patients, 2.8%).

Pneumothorax was also found in patients with lymphangiitis carcinomatosa (112 patients, 0.77%), endobronchial tumor obstruction (28 patients, 0.2%), and restrictive lung disease (23 patients, 0.16%).

Lung secondaries causing pneumothorax (1113 patients, 7.7%) were relatively not rare especially those with bone osteosarcoma. Contrary to most people's belief, pneumothorax in COPD patients (197 patients, 1.4%) or in asthma patients (181 patients, 1.3%) were not many. Rare causes of pneumothorax like tuberosus sclerosis only accounted for 3 patients (0.02% of total).

By looking through each step of chest tube drainage in managing patients with pneumothorax, we can solve most of the problems of 'difficult pneumothorax'. Literature review shows most of the time, it is due to incorrect chest drain insertion and subsequent daily monitoring. Although referral to thoracic surgeon is a good solution to 'difficult pneumothorax', sometimes it is difficult for patients with other comorbidities or having poor anaesthetic risk. At that situation, pleural fluid analysis, pleural space manometry, contrast CT thorax, and subsequent bronchoscopic endobronchial valve insertion may solve the problem.

Table 1. Root Cause Analysis to Peculiar Response of Pneumothorax to Chest Drainage

Level of analysis	Questions	Findings	Root Cause	Ask why?	Take action
What happened ? Unresolved pneumothorax	Failure of lung re-expansion or persistent air-leak after 5-7 days of chest tube drainage ● What areas are impacted? Prolong hospitalization and increase secondary complications	<ul style="list-style-type: none"> ● Increase cost of hospitalization ● Increase mortality 	<ul style="list-style-type: none"> ● Do not follow chest drain protocol ● Patient is unfit for surgery. 	<ul style="list-style-type: none"> ● Clumsy guideline and protocol ● Comorbidities making patient unsuitable for general anesthesia and surgery 	<ul style="list-style-type: none"> ● Simplify the protocol ● Employ medical advancement like endobronchial valve insertion
Why does it happen?	Steps in the process ● Chest drain insertion+/- suction ● underlying lung pathology	<ul style="list-style-type: none"> ● malposition of chest drain or connection problem ● lung pathology not yet corrected 	<ul style="list-style-type: none"> ● Not inserting chest drain correctly, not checking connection and tube kinking daily ● Not performing thorax imaging and pleural manometry ● Not considering the pressure profile 	<ul style="list-style-type: none"> ● incorrect position of chest drain, tube kinking, loculated pneumothorax, endobronchial obstruction, trapped lung and lung entrapment, interpleural communication in SBSP. ● alveolopleural/ bronchopleural fistula especially when patient is on positive pressure ventilation 	Daily check the chest drain system integrity <ul style="list-style-type: none"> ● Learn bedside US and ask for CT thorax ● perform pleural manometry with air aspiration ● Think of pressure change especially in SBSP
What are the most proximate factors?	<ul style="list-style-type: none"> ● Human factors ● ~Equipment factors 	<ul style="list-style-type: none"> ● Inadequate thoracic surgical service ● Inadequate imaging facilities 	<ul style="list-style-type: none"> ● Thoracic surgery not available in primary hospital ● Waiting time for CT thorax is 1-2 months 	<ul style="list-style-type: none"> ● High cost of setting a thoracic surgical unit in every hospital ● Lots of people waiting for CT thorax 	<ul style="list-style-type: none"> ● chest drain manipulation, interventional pulmonology ● make use of pleural manometry

(US: ultrasound, CT: computerized tomography, SBSP: simultaneous bilateral spontaneous pneumothorax)

It seems that chest drain insertion through the safe triangle after local anesthesia is simple. However, less than 50% junior doctors could mark the safe triangle correctly for chest drain insertion². If the chest drain is in the correct position, there should be swinging of the water column during patient's respiration and the gush of air coming out during patient's coughing. There should be no kinking of the chest drain and the connection between the chest drain and chest drain bottle should be checked daily. Nursing experiences in chest drain care vary as there is no consistent treatment regime and evidence-based nursing care³.

Thoracic ultrasound can identify minute pleural effusion, loculated pneumothorax, and thickened wall in empyema whereas CT thorax can identify endobronchial obstruction, mediastinal lymph nodes, trapped lung and lung entrapment, and possibly interpleural communication in 3-D reconstruction^{4,5}.

Patient, with trapped lung or lung entrapment, usually presents with pleural effusion. During chest tapping, the effusion cannot be completely drained due to chest pain⁶. And in fact, unexpandable lung is the most common cause of pneumothorax after chest tapping⁷. When you drain the fluid, air goes in the thoracic cavity due to the negative pressure you produced during fluid aspiration.

Lung entrapment is due to persistent active inflammation causing effusion and pleural restriction whereas trapped lung is due to old inflammation resulting in fibrous layer in pleural space. The acute phenomenon of lung entrapment is seen in inflammatory visceral pleura encasing a lung segment, or it can be due to increased elastic recoil in lymphangitis carcinomatosa, or due to endobronchial obstruction leading to lung collapse. Trapped lung is seen after infection, hemothorax, rheumatoid or uraemic pleuritis, and cardiac surgery. Analysis of pleural fluid showed lymphocytic exudate in lung entrapment and transudate in trapped lung⁸.

Normally the pleural pressure at functional residual capacity is -3 to -5cmH₂O. In lung entrapment, the pleural pressure, initially positive, falls gradually until more than 1.5-2L is draining out. At that time, the pleural pressure drops rapidly. Pulmonary elastance (Pel) is higher than 20 cmH₂O/L. In trapped lung, the pleural pressure drops steeply from the start of chest tapping with Pel more than 25 cmH₂O/L. Treatment varies according to the underlying cause, like laser recanalization and stenting in case of malignant endobronchial obstruction, and surgical decortication for trapped lung due to empyema thoracis.

Alveolopleural fistula presents with persistent air leak after the development of communication between the lung parenchyma distal to segmental bronchus and the pleural space. Bronchopleural fistula communicates segmental bronchi and the pleural space. Patient gets hypoxia and finally requires mechanical ventilation. We aim at using low tidal volume, low PEEP (positive end-expiratory pressure), less positive pressure breaths to promote fistula healing. Suction through the chest drain is discontinued⁹. We can connect the underwater seal to the inspiratory limb of

ventilator circuit causing intermittent inspiratory chest drain occlusion or connect the underwater seal to the expiratory limb of ventilator circuit to limit the air-leak during expiration. Other methods include independent lung ventilation, high frequency ventilation and closure of fistula by surgery or endobronchial valve insertion¹⁰⁻¹³.

Simultaneous bilateral spontaneous pneumothorax (SBSP) describes the occurrence of bilateral pneumothorax at the same instant of time. If the pleural spaces are separate, SBSP can be treated by bilateral chest tube drainage with suction followed by talc pleurodesis. When there is pleuro-pleural communication, the suctional forces applying to the two pleural spaces will cancel each other and the trans-pulmonary pressure cannot be reached the critical level to inflate the lungs. As the lung defect causing the pneumothorax is healed up in a week or so, there will be no air-leak seen in the chest drain bottle. The lungs act as one mass, being pulled to the left or the right leading to left or right pneumothorax, respectively. Finally, both lungs are not fully expanded. It can be corrected by surgical pleurodesis or ways to increase the intrapulmonary pressure followed by talc pleurodesis¹⁴⁻¹⁵.

4. Conclusions

Two lungs and two pleural spaces work in harmony according to the pressure change. Chest tube drainage system, with or without suction, solves most cases of pneumothorax. To maintain a negative pleural pressure, we need an isolated pleural space, patent tubings, together with an expandable lung. Performing the root cause analysis of each step will solve the problem of peculiar response of pneumothorax to chest drainage.

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