


# Positive pressure–assisted pleural aspiration: A case report of a novel procedure and a review of literature

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## Abstract

Drainage of a pleural effusion is done either by inserting an intercostal tube or by aspirating pleural fluid using a syringe. The latter is a time-consuming and labour-intensive procedure. The serious complications of pleural aspiration are the development of a pneumothorax and re-expansion pulmonary oedema. We describe an observation made during a pleural aspiration in a patient who was on positive pressure ventilation. We explain the physiological basis for the observation, the safety of the procedure and its potential to reduce complications by reviewing the literature. A 56-year-old Sri Lankan female patient with end-stage kidney disease presented with fluid overload and bilateral pleural effusions. She was found to have concurrent COVID pneumonia. The patient was on bilevel positive airway pressure, non-invasive ventilation when pleural aspiration was done. The pleural fluid drained completely without the need for aspiration, once the cannula was inserted into the pleural space. Onelitre of fluid drained in 15 min without the patient developing symptoms or complications. Positive pressure ventilation leads to a supra-atmospheric (positive) pressure in the pleural cavity. This leads to a persistent positive pressure gradient throughout the procedure, leading to complete drainage of pleural fluid. Pleural fluid drainage in mechanically ventilated patients has been proven to be safe, implying the safety of positive pressure ventilation in pleural fluid aspiration and drainage. It further has the potential to reduce the incidence of post-aspiration pneumothorax by reducing the pressure fluctuations at the visceral pleura. Re-expansion pulmonary oedema is associated with a higher negative pleural pressure during aspiration, and the use of positive pressure ventilation can theoretically prevent re-expansion pulmonary oedema. Positive pressure ventilation can reduce the re-accumulation of the effusion as well. We suggest utilizing positive pressure ventilation to assist pleural aspiration in suitable patients.

## Keywords

Pleural effusion, positive pressure, aspiration, re-expansion pulmonary oedema, pneumothorax

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## Introduction

Pleural effusion, the collection of fluid in the pleural space, is a manifestation of a multitude of diseases: both systemic and pulmonary. Drainage is recommended for large effusions, which is either by intercostal tube insertion or aspiration. Aspiration is done by inserting a needle into the pleural cavity and manually applying negative pressure through a syringe connected to the needle. The fluid accumulating in the syringe is expelled through a free port using a three-way tap.<sup>1</sup> This is a labour-intensive and time-consuming process.

Furthermore, the recommended method of pleural aspiration has complications such as re-expansion pulmonary oedema (RPO) and post-aspiration pneumothorax (PAP),

which can be life-threatening. The incidence of RPO is around 1% and can have a mortality rate as high as 21%.<sup>2</sup> RPO occurs increasingly with a longer duration and a higher volume of the effusion. The incidence of PAP has fallen drastically from 4%–30% to 1.3%–6.7% with the utilization of ultrasound to guide pleural aspiration.<sup>3</sup> However, a small proportion of PAP is due to micro-tears in the visceral pleura,

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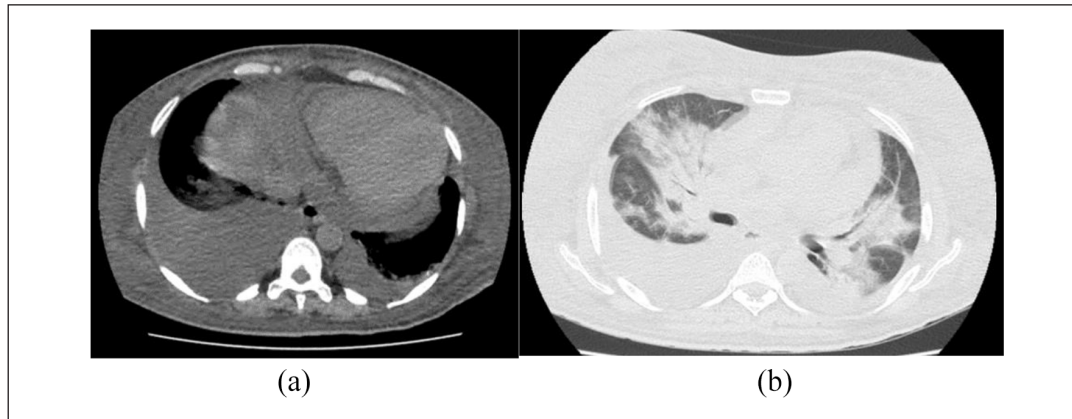
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**Figure 1.** (a) NCCT-chest demonstrating bilateral pleural effusions (right > left) and (b) HRCT-chest demonstrating parenchymal changes of COVID pneumonia.

caused by pressure inequalities within the pleural cavity.<sup>4</sup> It has been found that the negative suction pressure promotes the formation of micro-tears.

A less time-consuming and safer method for pleural aspiration can lead to better patient outcomes and practitioner convenience. We propose utilization of positive pressure ventilation to assist pleural aspiration, based on an observation made in a patient.

The following text contains the observations made during a pleural aspiration procedure in a patient who was connected to a positive airway pressure, non-invasive ventilation (NIV) circuit. It is followed by a discussion on the pressure dynamics of pleural effusions during drainage and during positive pressure ventilation, separately, and an argument for the higher efficacy and safety of pleural aspiration when assisted by positive pressure ventilation. Finally, the existing literature on instances where pleural drainage/aspiration was done in patients on mechanical ventilation is described.

## Case

A 56-year-old Sri Lankan female having diabetes, hypertension and anuric end-stage kidney disease (ESKD) presented with progressive exertional dyspnoea, orthopnoea, paroxysmal nocturnal dyspnoea and generalized body oedema for 5 days. She was prescribed with thrice weekly haemodialysis but had not complied for 2 weeks and had poorly adhered to fluid restriction. Physical examination revealed generalized body oedema with bilateral pleural effusions, right more than left and ascites. The oxygen saturation ( $\text{SpO}_2$ ) on air was 90%. The serum creatinine was 7.1 mg/dL (0.55–1.02). The COVID rapid antigen test was positive, and non-contrast computed tomography (NCCT) demonstrated bilateral pleural effusions (Figure 1). The high-resolution computed tomography (HRCT) had parenchymal ground glass opacities and consolidations compatible with COVID pneumonia (Figure 1).

The patient was haemodialyzed immediately and daily for the next 4 days with an average daily ultra-filtration of 3.5 L. However, by day 4, she required bilevel positive airway pressure (BPAP) NIV to maintain a  $\text{SpO}_2$  of 94% due to rising oxygen requirements from worsening COVID pneumonia. A right-sided therapeutic thoracocentesis was done to improve her lung expansion. The aspirated pleural fluid was transudative. The pleural fluid analysis is given in Table 1.

The procedure was done with ultrasound localization while the patient was on the BPAP (EPAP (Expiratory Positive Airway Pressure) – 10 cm  $\text{H}_2\text{O}$ , IPAP (Inspiratory Positive Airway Pressure) – 18 cm  $\text{H}_2\text{O}$ , fraction of inspired oxygen ( $\text{FiO}_2\%$ ) – 70%), using an 18-gauge thoracocentesis catheter. The pleural fluid kept on draining spontaneously without the need for aspiration. One litre of fluid drained spontaneously within 15 min without any symptoms. A left-side thoracocentesis was done in a similar fashion the following day, with 300 mL draining spontaneously within 10 min. The post-procedure chest X-ray (Figure 2) and ultrasound revealed complete resolution of the effusions without evidence of pneumothorax.

## Discussion

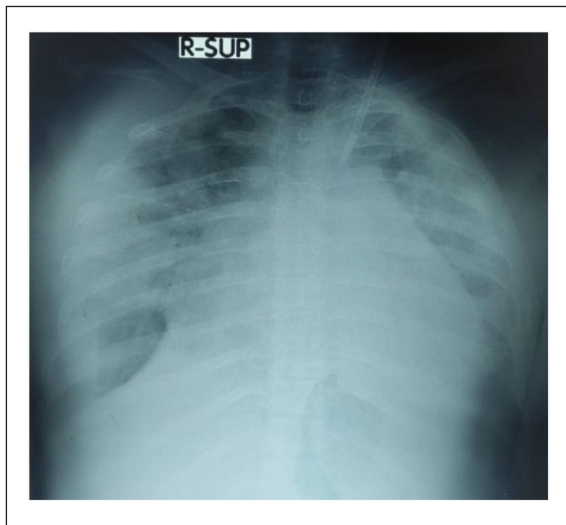
The normal human pleural space has a pressure of  $-4$  cm  $\text{H}_2\text{O}$  at rest, compared to the atmospheric pressure. Contraction of the diaphragm and external intercostal muscles during inspiration further lowers the pleural pressure ( $-6$  to  $10$  cm  $\text{H}_2\text{O}$ ) and leads to lung expansion. During forced inspiration against increased airway resistance, it might be as low as  $-100$  cm  $\text{H}_2\text{O}$ . The reverse occurs during expiration.<sup>5</sup>

In positive pressure ventilation, the pleural pressure is higher than atmospheric air throughout, with peaks and troughs corresponding to inspiration and expiration, respectively.<sup>6,7</sup> Key points about pleural pressures are given in Table 2.

**Table 1.** Pleural fluid analysis (with corresponding serum biochemistry).

Pleural fluid	Value	Serum	Value	Normal range
pH	9.0			
Protein	2.3 g/dL	Total protein	6.1 g/dL	6.4–8.3
Glucose	84 mg/dL	Blood glucose	128 mg/dL	80–130
LDH	187 U/L	LDH	499 U/L	125–220
Cholesterol	41 mg/dL			
Albumin	1.1 g/dL	Albumin	2.6 g/dL	3.5–5.2
ADA	4.4 U/L			
Pleural fluid microscopy				
Polymorphs	20 cells/mm <sup>3</sup>			
Lymphocytes	55 cells/mm <sup>3</sup>			
Red blood cells	3700 cells/mm <sup>3</sup>			

LDH: lactate dehydrogenase; ADA: adenosine deaminase.



**Figure 2.** Post-aspiration chest X-ray demonstrating complete clearance of the effusions. Note the underlying lung shadows compatible with COVID pneumonia.

The pleural pressures in effusions depend on the underlying pathology and the presence or absence of lung collapse. Commonly, pleural effusions have a positive pressure in the absence of positive pressure ventilation of around 5 cm H<sub>2</sub>O (effusions due to volume overload, right heart failure, decompensated hepatic failure), less so if there is associated lung collapse. A negative opening pleural pressure can be seen when the effusion is due to a trapped lung.<sup>8</sup> This difference in the pleural opening pressures has been used to identify the aetiology of effusions.<sup>9–11</sup>

The change in pleural pressures during withdrawal of fluid depends on the underlying pathology and is given in Figure 3. With expandable lungs, the pleural pressure change minimally as fluid is withdrawn. When it is close to complete drainage, there is a terminal deflection of pressure towards the normal pleural pressure. The pleural elastance is defined as the change in pleural pressure with the removal of

a unit volume of fluid. The normal pleural elastance is less than 14.5 cm H<sub>2</sub>O/L. With expandable lungs, the pleural elastance is normal throughout the process of pleural effusion aspiration.<sup>8,9</sup>

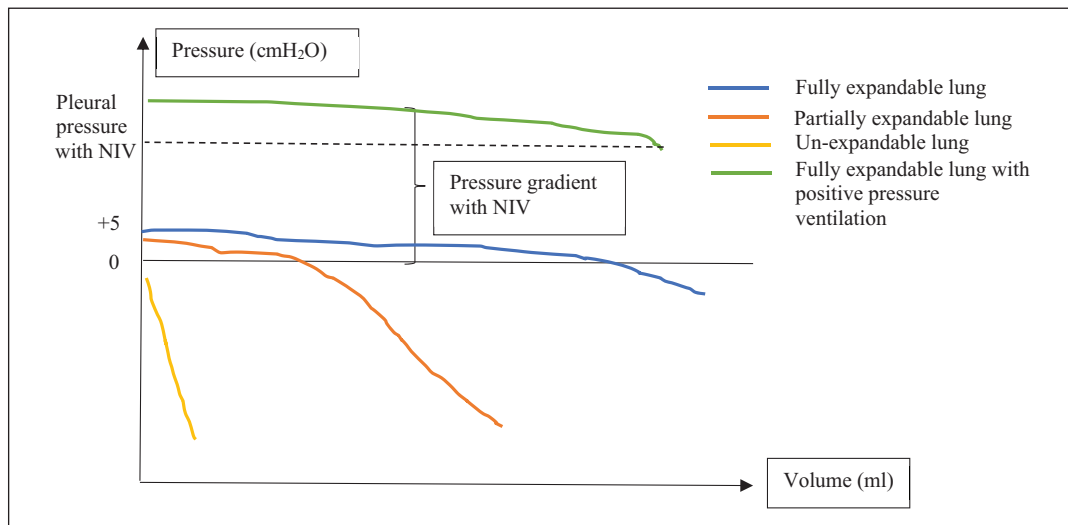
The pleural pressure dynamics are different when the lung is only partially expandable, as in lung entrapment due to malignancy, infection of the lung parenchyma or visceral pleura. During the initial phase of fluid removal, the pleural pressure decrease only slightly as the lung expands and occupies the volume of the removed fluid. A steeper pressure drop is seen towards the latter part of drainage as the lung expansion is reduced beyond a certain level. This results in a biphasic pressure volume curve. The pleural elastance is likewise biphasic, which is equal to or less than 14.5 cm H<sub>2</sub>O/L during the initial stages and more than 14.5 cm H<sub>2</sub>O/L during the latter stage.<sup>8,9</sup>

With a non-expandable trapped lung, the pleural effusion is secondary to the reduction in lung volume (pleural effusion ex vacuo). There is a rapid and steep monophasic decrease in pleural pressure with the removal of fluid from the pleural space. As a result, pulmonary elastance is more than 14.5 cm H<sub>2</sub>O/L (often greater than 25 cm H<sub>2</sub>O/L) throughout the procedure.<sup>8,12</sup> After the removal of 200–500 mL of fluid, the pleural pressure fluctuation with each cycle of respiration begins to increase, thus increasing the risks of RPO and PAP.<sup>11,13</sup> These changes in pressures during a thoracic paracentesis are used to predict the presence of a trapped lung.

We observed that the pleural fluid drained rapidly and completely. It did not require the manual creation of a negative pressure within the syringe. We hypothesize that the positive airway pressures from BPAP led to higher pleural pressures that facilitated drainage, as positive pressure ventilation leads to supra-atmospheric pressures in the normal pleural space.<sup>6,7</sup> Therefore, the positive pressure gradient between the pleural space and atmosphere throughout the procedure facilitated complete drainage without the need for aspiration. We propose using positive airway pressure to assist pleural drainage in effusions with fully expandable

**Table 2.** Facts on pleural pressures..**Highlights on pleural pressures**

- In health, pleural pressures are not uniform throughout the pleural space. There is a gravity mediated pressure gradient with highest pressures in the lung bases.
- In a pneumothorax, the pressures are equal throughout the pleura while in an effusion, the gradient is preserved (1 cm H<sub>2</sub>O/cm).
- Two types of pleural pressures are measured:
  - Pleural liquid pressure.
  - Pleural surface pressure.
- There are two methods of pleural pressure measurements:
  - Using water manometers.
  - Using electronic manometers.

**Figure 3.** Changes of pleural pressure with aspiration of pleural fluid (not drawn to scale).

lungs. The effects on partially expandable or non-expandable lungs should be further researched.

The three main mechanisms of developing PAP are damage to the underlying lung by the aspiration needle, accidental introduction of air into the pleural space through the needle and the creation of small visceral pleural tears due to local fluctuations in pleural pressures.<sup>14</sup> Using ultrasound to guide the aspiration has largely prevented injury-induced pneumothorax, while a closed aspiration/drainage system attempts to reduce the formation of pneumothorax through the syringe. Visceral pleural tears are probably created by non-uniform stress distribution over the pleura, leading to transient airspace-pleural fistulae.<sup>4</sup> This phenomenon is observed more often in cases of trapped lungs. The role of negative pleural pressure in the development of pneumothorax during pleural fluid removal may be supported by observations that the use of vacuum bottles was an apparent risk factor for pneumothorax (odds ratio (OR)=4.6,  $p < 0.01$ ) and that pneumothorax following the use of vacuum bottles significantly more often required chest tube insertion.<sup>15–18</sup>

Thoracentesis has been found to be safe in patients on positive pressure ventilation. A meta-analysis done in 2011 with 19 having with a cumulative total of 1124 patients

assessed the safety of draining pleural effusions in mechanically ventilated patients. They identified a low rate of complications with a pooled mean incidence of pneumothorax in 3.4% and haemothorax in 1.6%.<sup>19</sup> A blinded study<sup>20</sup> in Brazil randomized 150 patients who had a chest drain inserted for pleural effusions into three groups. Two groups received a sham positive airway pressure of 4 cm H<sub>2</sub>O with (experimental group 1) and without (control group) respiratory and mobilization techniques to hasten fluid drainage. The other group receives a positive airway pressure of 15 cm H<sub>2</sub>O along with respiratory and mobilization techniques (experimental group 2). The adverse effect rates were similar between the groups, which indicates that the utilization of positive airway pressure to assist pleural fluid aspiration is probably safe, although this needs further evaluation with safety studies. In addition, it was found that the experimental group 2 had faster drainage, reduced antibiotic use and a reduced incidence of pneumonia.

RPO is a rare but life-threatening complication of pleural fluid aspiration, associated with the removal of large amounts of pleural fluid. This has led to the recommendation by the British Thoracic Society (BTS) to not aspirate more than 1.5L during a single procedure. The pathophysiology of

**Table 3.** Starling forces in the formation of pleural fluid.<sup>28</sup>

$$\text{Flow} = K ([P_c - P_p] - \sigma[\pi_c - \pi_p])$$

$K$  – filtration coefficient of the capillary wall.

$P_c$  – hydrostatic pressure in the pleural capillaries.

$P_p$  – hydrostatic pressure in the pleural space.

$\sigma$  – reflection coefficient for total protein (which defines how easily a protein can move across a pore of a certain size).

$\pi_c$  – protein osmotic pressure in the pleural capillaries.

$\pi_p$  – protein osmotic pressure in the pleural space.

RPO is not completely understood; the prevailing theories are based on analysis of oedema fluid. Some studies have found the oedema fluid to be exudative, whereas some studies have found it to be transudative. In studies which found the oedema fluid to be exudative and had inflammatory cells, it was hypothesized that the mechanism of RPO is due to inflammation secondary to sudden expansion and ventilation of chronically collapsed, hence ischemic lungs, contributed by oxidative injury caused by the increase in partial pressures of oxygen.<sup>21</sup> A study done by Sue et al. demonstrated the oedema fluid to plasma protein ratio to be less than 0.65, resulting them to conclude that RPO is due to changes in hydrostatic pressures that occurred during lung expansion.<sup>22</sup> It is believed that the occurrence of RPO is related to pleural pressure drop, rather than to the volume of removed pleural fluid.<sup>11</sup> Grabczak et al.<sup>11</sup> have described the importance of real-time pleural manometry during therapeutic thoracocentesis to prevent RPO. The BTS recommends terminating thoracocentesis if the pleural pressure drops to less than  $-20$  cm H<sub>2</sub>O during thoracocentesis.<sup>1</sup> The arbitrary value of  $-20$  cm H<sub>2</sub>O is derived from animal studies, and is challenged by some to be a too conservative target.<sup>23</sup>

Understandably, management of RPO is not well established; the BTS suggests using continuous positive airway pressure (CPAP), in addition to intense monitoring. There are several case reports where CPAP was used successfully in treating RPO.<sup>24,25</sup> Whether CPAP can be used for the prevention of RPO, thereby permitting larger volumes of fluid to be drained at a time, is still unknown. A study in 2019 compared the changes in pleural pressures during therapeutic thoracocentesis with and without a CPAP of 5 cm H<sub>2</sub>O.<sup>26</sup> Patients in the CPAP group had a significantly lower pleural elastance. ‘No patient in the CPAP group had a pleural pressure less than  $-20$  cm H<sub>2</sub>O at termination of the procedure’, while eight (33%) control group patients developed a pressure lower than  $-20$  cm H<sub>2</sub>O.

Coughing leads to the generation of a positive airway pressure against a closed glottis and hence has a positive pleural pressure. In one study<sup>27</sup> with six patients with pleural effusions, it was found that cough-related elevation of pleural pressure persisted even when the cough had stopped, and the authors argued that coughing during the procedure could prevent the incidence of RPO. Further studies should be conducted to assess whether positive pressure ventilation-assisted pleural aspiration can prevent RPO.

Formation of pleural fluid in the physiological state can be explained using the Starling forces, as given by the equation in Table 3.<sup>28</sup>

The pleural space, being a unique compartment having a negative pressure, ‘pulls’ fluid out of the capillaries into the pleural space, which is promptly reabsorbed by the lymphatics of the parietal pleura. Pleural effusions form when the production of pleural fluid exceeds the maximum rate of fluid reabsorption, which is about 40 times higher than the physiological state.<sup>29</sup> Theoretically, a positive pleural pressure can lead to a reduction in pleural fluid formation and can increase pleural fluid reabsorption. A Brazilian study compared the combination of intermittent CPAP and anti-tuberculous treatment (ATT) with ATT alone, in patients with pleural effusions due to tuberculosis. The study demonstrated a statistically significant reduction in the pleural effusions after 4 weeks, in patients who received CPAP.<sup>30</sup> Therefore, there might be a place for positive pressure ventilation in the prevention of re-accumulation of pleural effusions after therapeutic thoracocentesis.

However, the complications inherent to NIV act as drawbacks to using it to support pleural aspiration. NIV can cause minor difficulties such as mask-related discomfort or major complications such as aspiration pneumonia and haemodynamic instability.<sup>31</sup> Therefore, the decision to use NIV to assist pleural aspiration should be based on clinical grounds after weighing the risks and benefits.

## Conclusion

We propose a novel method to facilitate pleural fluid aspiration and drainage, that is, positive pressure-assisted pleural aspiration. We have discussed the physiological basis for its use with fully expandable lungs. It is likely to be safe and may prevent pneumothorax, RPO and decrease re-accumulation of pleural effusions after the procedure. Its efficacy and the safety with non-expandable and partially expandable lungs should be assessed with further studies.

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## Author contributions

Dr P.S.R. conceptualized the procedure, did the literature review and wrote the manuscript. Dr R.K. edited and contributed in writing of the manuscript. Professor S.J. assisted in conceptualization, and literature review and editing the manuscript.

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## Ethical approval

Ethical approval was not obtained as only an observation made during patient care is reported with the consent of the patient.

## Informed consent

Written informed consent was obtained from the patient for their anonymized information to be published in this article.

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