Safety and Efficacy of Vacuum Bottle Plus Catheter for Drainage of Iatrogenic Pneumothorax

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Abstract

Iatrogenic pneumothorax is common after thoracic procedures. For pneumothorax larger than 15%, simple aspiration is suggested. This clinical trial (NCT03724721) assessed the safety and efficacy of vacuum bottle plus non-tunneled catheter air drainage, which has long been performed in many institutions. From August 2018 to February 2020, patients older than 20 years of age who developed iatrogenic pneumothorax were prospectively enrolled. Totally 21 patients underwent vacuum bottle plus catheter drainage. The median size of pneumothorax was 19.6%, as measured by Rhea's method. Of the 21 patients, 15 had successful air drainage, and the remaining 6 patients required subsequent pigtail placement. The end-expiratory intrapleural pressure of all patients remained less than -20 cmH_2O during drainage. The median duration of hospitalization was 2 (interquartile range [IQR], 1-4) days. No procedure-related complication was observed. A retrospective analysis of patients who received conservative treatment showed that the median duration of hospitalization was longer in patients with larger pneumothorax (1 day vs. 5 days [IQR, 1-1 day vs. 3-7 days]). This study showed that vacuum bottle plus catheter drainage of iatrogenic pneumothorax is a safe and efficient procedure. It is recommended as initial management of stable iatrogenic pneumothorax with size larger than 15%.

Introduction

Iatrogenic pneumothorax is a common complication resulting from many pulmonary interventions. The reported incidence of iatrogenic pneumothorax is as follows: 0.8–1.4% in patients undergoing radial endobronchial ultrasound-guided transbronchial lung biopsy, approximately 2–6% among patients undergoing thoracentesis, 0.6–9% in patients undergoing echo-guided biopsy, and as high as 42% among patients undergoing CT (computed tomography)-guided lung biopsy[1–8]. The British Thoracic Society guidelines in 2010 suggested that observation alone is adequate for majority of the cases of iatrogenic pneumothorax and that, if intervention is required, simple aspiration be considered[9,10]. Several studies have reported that catheter aspiration for iatrogenic pneumothorax is cost effective and with few complications[10–12].

The introduction of thoracentesis to remove either fluid or air through vacuum bottle drainage system can be traced back to the 1950s and it had been widely adopted in many clinical settings[13,14]. Compared with manual aspiration, vacuum bottle assisted thoracentesis requires less time and allows uninterrupted drainage without repeatedly manipulating 3-way stopcock. Although this procedure had long been adopted by many medical facilities in Taiwan, it has rarely been described in the literature, especially data regarding its safety and efficacy. To the best of our knowledge, only one pilot study documented the complication rate of vacuum bottle fluid drainage, which was 9.8%[14]. However, the study was conducted at a single center where vacuum bottle drainage was not routinely employed. In addition, the flow rate of fluid drainage, a key component when applying negative pressure drainage system, was not reported in the study. Further, data on air removal by vacuum bottle drainage system were lacking. Thus, through the current study, we aim to investigate the safety and efficacy of this procedure to provide an evidence-based approach for this routine clinical practice.

Methods

Study design and data collection

This prospective interventional study was conducted in the general chest ward in National Taiwan University Hospital, a tertiary center in northern Taiwan, from August 2018 to February 2020. We enrolled adult patients who developed iatrogenic pneumothorax after undergoing invasive thoracic procedures.

The inclusion criteria were patients with radiographic evidence of pleural line after lung biopsy (echo-guided, bronchoscopic, or CT-guided biopsy) and whose size of pneumothorax was more than 15%, measured by Rhea's criteria[15]. The exclusion criteria were age younger than 20 years, bleeding tendency, and hemodynamic instability. Those who fulfilled the inclusion criteria and agreed to participate were prospectively enrolled for the safety study. In this institute, patients with size of iatrogenic pneumothorax less than 15% would receive conservative treatment, namely oxygenation therapy and image monitoring first. If the size of pneumothorax enlarged or hemodynamic instability occurred, further intervention would be proceeded. These subjects were retrospectively evaluated for the efficacy study. The study protocol was approved by the Research Ethics Committee of National Taiwan University Hospital (No.201805105DINA). This clinical trial was registered at clinicaltrials.gov with identifier NCT03724721 on 30/10/2018.

Written informed consent was obtained from each subject before enrolment. The whole research process was performed in accordance with the Declaration of Helsinki.

Study protocol

The standardized procedure for drainage of pneumothorax by vacuum bottle is described in the Fig. 1 and Supplementary text S1 online. To avoid rapid intrapleural pressure change and suction trauma, we make sure the flow rate of air drainage was slow by keeping the air bubble in one straight line throughout the procedure (Supplementary video S2).

The flow chart of enrollment was presented in Fig. 2. Patients with either small pneumothorax only visible on CT or large pneumothorax and unstable vital signs were excluded. Those with pneumothorax size small than 15% and stable vital signs received oxygenation only and was closely monitored by image once daily. Participants with stable pneumothorax with size larger than 15% would undergo vacuum bottle plus catheter drainage under informed consent.

Data collection and outcome measure

In the prospective study, the subjects' baseline characteristics and study parameters were recorded, including age; gender; underlying disease; chest X-ray before, immediately after, and on the next day after the drainage; thoracic procedures (thoracentesis, echo-guided biopsy, bronchoscopic biopsy, CT-guided biopsy); and the size of the pneumothorax, as defined by the Rhea's criteria. The primary outcomes included the rate of successful drainage with the definition being persistent lung expansion immediately after, and on the next day of the procedure and the end-expiration intrapleural pressure before, at 30-second intervals during, and at the end of the procedure. The secondary outcomes included the patient's pain recorded in the numeric pain rating scale from 0 to 10 during the procedure and any possible side effects, such as re-expansion pulmonary edema, hemothorax, and subsequent tension pneumothorax.

In the retrospective analysis that evaluated the efficacy of the procedure, the baseline demographics of the subjects in the control group were recorded in the same way as in the intervention group. In this center, patients who were receiving oxygenation only treatment for pneumothorax underwent chest X-ray every day and were not allowed to be discharged until the chest X-ray showed near total resolution of pneumothorax. Because of prolonged admission that occurred often owning to the requirement of extra hospitalization such as waiting for other diagnostic studies or treatments for underlying diseases, the event-free date was defined as the date when the primary care team shifted the problem of post-biopsy pneumothorax from the list of active problems to inactive ones. For outcome assessment, the control subjects were further divided into two subgroups by the amount of initial pneumothorax, with 10% as the cutting point.

Statistical analysis

Baseline characteristics are expressed as median with interquartile range (IQR), mean with standard deviation (SD), or number with proportion, as appropriate. Continuous variables were compared using Wilcoxon rank-sum test or Wilcoxon signed-rank test, as appropriate. Categorical data were compared using the Chi-square test or Fisher's exact test. A *P*-value of $< .05$ was considered statistically significant. All statistical analyses were performed using STATA version 14 software (StataCorp LLC, College Station, TX, USA).

Results

Characteristics of the study cohort

A total of 74 patients were screened, and 21 patients who met the inclusion criteria and provided informed consent were enrolled as the intervention group. Another 31 patients who had radiographically obvious pneumothorax but pneumothorax size less than 15% by Rhea's criteria received oxygenation only. These patients were retrospectively reviewed and designated as the oxygen only group (Fig. 2). The baseline demographics of all subjects are summarized in Table 1. The median age of the subjects was 66.5 (IQR, 61-70) years, and 27 of them were male. Among the 52 iatrogenic pneumothorax events, CT-guided biopsy accounted for 40 events. Only one patient had a previous experience of pneumothorax, which was also iatrogenic. In total, 41 patients had lung cancer and 16 of them underwent rebiopsy for progressive disease. The baseline characteristics between the intervention group and control

group were similar, except that patients in the control group were heavier than those in the intervention group (*P*= .043). However, the body mass index (BMI) did not statistically differ between the two groups (*P*= .061).

Table 1
Baseline Demographics of the Study Subjects

	Total	Intervention group	Control group	p value
	(n=52)	(n=21)	(n=31)	
Age, year	66.5(61,70)	64(62,69)	68(59,73)	0.582
Male	27(51.9%)	10(47.6%)	17(54.8%)	0.609
Height, cm	160(152.8,166.8)	158.3(152.6,164.7)	162(152.8,167.3)	0.244
Weight, kg	61.5(55.2,68.7)	58.4(47.6,64.8)	63.1(57.1,71.6)	0.043
BMI	23.3(21.1,26.3)	22.4(20.6,23.7)	24.6(21.4,27.0)	0.061
Current smoker	18(34.6%)	7(33.3%)	11(35.5%)	1
Procedure				
CT-guided biopsy	40	14	26	0.518
Echo guided biopsy	2	1	1	
Bronchoscopic biopsy	4	2	2	
Thoracentesis	6	4	2	
Underlying disease				
Lung cancer	41	17	24	0.501
COPD	8	2	6	
Asthma	3	0	3	
Bronchiectasis	1	0	1	
Previous pneumothorax	1	1	0	
Data are presented as n (%) or median (interquartile range).				
COPD: chronic obstructive pulmonary disease; control group: oxygenation only group.				

Safety analysis

The median size of pneumothorax among patients in the intervention group was 19.6% (IQR, 16%-24%) by Rhea's method. Pneumothorax improved without persistent air leakage in 15 patients in the intervention group. A total of 6 (28.6%) patients had persistent air leakage and underwent pigtail placement (Table 2). The end-expiratory intrapleural pressure of all patients remained less than −20 cmH_2O during drainage (Supplementary Fig. S1). The median time of air removal was 90 (IQR 60-180) seconds. The median numeric pain rating scale scores out of 10 before, during (30 seconds after initiation), and after the procedure in patients in the intervention group who were receiving vacuum were 1, 1, and 0, respectively (Supplementary Fig. S2). No procedure-related bleeding, infection, re-expansion pulmonary edema, or mortality was observed. The procedure cost of vacuum bottle plus non-tunneled catheter drainage was approximately 49 United States dollar (USD) and that of 8-Fr. pigtail placement with water sealed drainage system was 136 USD.

Table 2
Patient Outcomes

	Intervention group	Control group	p value
	(n=21)	(n=31)	
Amount (%)	19.6(16,24)	8.8(6.2,13.2)	<0.05
Right site	17	18	0.084
Outcome			
Lung expansion	15 (71.4%)	30 (96.8%)	0.013
Pigtail rescue	6 (28.6%)	1	
Data are presented as n (%) or median (interquartile range).			
control group: oxygenation only group			

Efficacy and subgroup analysis

In the intervention group, the median duration from the occurrence of pneumothorax to event-free date was 2 (IQR, 1-4) days in patients who underwent vacuum bottle plus non-tunneled catheter drainage only and 5 (IQR, 5-8) days in patients who underwent subsequent pigtail placement. In the control group, the median duration from the occurrence of pneumothorax to event-free date was only 1 day (IQR, 1-5 days) for patients who received oxygenation only and 4 days for one patient who experienced enlargement of pneumothorax and received air aspiration. Patients in the oxygenation only group were further stratified into 2 subgroups by the amount of initial pneumothorax, with 10% as the cutting point. The duration from the occurrence of pneumothorax to event-free date was 1 day (IQR, 1-1day) in patients whose initial pneumothorax was less than 10%, and 5 (IQR, 3-7) days in patients whose initial pneumothorax was equal to or greater than 10% (P< .05) (Fig. 3).

Discussion

Through this prospective study, we reported that the vacuum bottle plus non-tunneled catheter drainage of pneumothorax is a safe and efficacious procedure. In addition, we provide a detailed clinical course concerning oxygenation only with watchful waiting, simple air aspiration, and pigtail drainage, which may aid decision -making regarding post procedural pneumothorax.

Simple aspiration of air or fluid through catheter plus vacuum bottle has been performed in many hospitals in Taiwan. Compared with manual drainage, a vacuum bottle-assisted drainage facilitates continuous removal of air or fluids, diminishing the necessity of repeated 3-way stopcock and syringe manipulation which could be annoying and time-consuming during large-volume thoracentesis. Yamagami *et al.* evaluated 72 post-CT guided biopsy pneumothoraxes that required needle aspiration; the mean volume of air was 527 mL, with the largest volume being 2700mL. In a similar study conducted by Faruqui *et al.*, the mean aspirated air volume was 680 (200-2000) mL. A 50-mL syringe would require approximately 10 to 50 repeated manipulations, which would be laborious and time-consuming[16,17].

However, the possibility of large negative pressure exerted by the vacuum bottle on the pleural space makes the safety of this procedure a concern. A rapid re-expansion of the collapse lung may lead to so called re-expansion pulmonary edema. Although rare, the related mortality might be as high as 20%[18]. The main factors contributing to re-expansion pulmonary edema include collapse of the lung for more than 3 days, use of negative intrapleural pressure to rapidly re-expand the collapse lung, and the removal of more than 1 L of effusion. Feller-Kopman *et al.* suggested that large-volume thoracentesis is feasible as long as the patient is symptom-free or the end-expiration intrapleural pressure is maintained below -20 cmH_2O[19]. In this study, the time from the development of pneumothorax to intervention were all within hours. Besides, the air drainage flow rate was slow by keeping the formation of air bubble in one straight line throughout the procedure. Lastly, by intermittently monitoring intrapleural pressure during negative pressure drainage, we proved that the vacuum bottle-assisted drainage is safe, and the end-expiratory intrapleural pressure remained less than 20 cmH_2O throughout the procedure (Supplementary Fig. S1).

In the current cohort study, 15 out of 21 (71.4%) patients achieved lung expansion by vacuum bottle plus non-tunneled catheter drainage, with the remaining 6 (28.6%) patients requiring pigtail catheter drainage as a rescue. No patient experienced persistent air leak. This finding is comparable with previous studies, which reported a lung expansion rate of approximately 57.1–94.1% by manual needle aspiration[1,9,16,17,20–23]. The median event-free period in this study was 2 (IQR, 1-4) days in the vacuum bottle plus non-tunneled catheter drainage only group. This finding is compatible with previous studies, wherein the median hospital duration ranged from 1 to 5 days (Table 3) [10–12,16,17,20–24]. The event-free duration was almost equal to that in the subgroup of patients in the oxygen only group with size of pneumothorax less than 10% and shorter than that in patients with larger size of pneumothorax in this cohort. Moreover, all patients who required subsequent pigtail placement achieved full lung expansion in this study, with an event-free period of 5 (IQR, 5-8) days, which was comparable to the event-free duration of 6 to 7 days with primary tube thoracostomy reported in previous studies[16,20].

Table 3
Comparison of Studies Employing Simple Air Aspiration in Patients with Iatrogenic or Traumatic Pneumothoraxes

	Study design	Enrolment criteria	Method of aspiration	Patient number and success rate*, n (%)	Procedure time and hospital duration	Pain, costs, and complications
Chen *et al.*, 2021	Prospective cohort study	Inclusion: Radiographic evidence of pleural line after lung biopsy and the size of pneumothorax ≥ 15% (Rhea's criteria) Exclusion: Age < 20 years, bleeding tendency, and hemodynamic instability	16G IV catheter, a 3-way stopcock, drainage set, and vacuum bottle	Total patients: 21 Success: 15 (71.4%)	Procedure time: median 90 (IQR 60-180) seconds Hospital duration: Median 2 (IQR 1-4) days	Pain: - before: median 1 (IQR 0-1) - during: median 1 (IQR 0-1) - after: median 0 (IQR 0-1) Cost: Vacuum bottle plus catheter aspiration: 49 USD Pigtail drainage: 136 USD Complications: nil
Domokos *et al.*, 2020[20]	Retrospective cohort study	Inclusion: Pneumothorax with visible rim ≥ 2 cm between the lung margin and the chest wall at the level of the hilum Exclusion: N/A	16-G or 18-G over the needle cannula, a 3-way stopcock, and 50-mL syringe	Total patients:14 Success: 8 (57.1%)	Hospital duration: 2.0 (IQR 2.0-3.25) days	

G: gauge, IV: intravenous, N/A: not applicable

*Success was defined as aspiration only without subsequent rescue method such as tube thoracostomy.

**The study did not separate patients with pneumothorax of different etiologies (included both spontaneous pneumothorax and traumatic pneumothorax).

	Study design	Enrolment criteria	Method of aspiration	Patient number and success rate*, n (%)	Procedure time and hospital duration	Pain, costs, and complications
Parlak *et al.*, 2012[22]	Prospective randomized controlled study	Inclusion: age 18-85 years, first symptomatic pneumothorax or asymptomatic with size ≥ 20% (Light's index) Exclusion: Pregnancy, severe comorbidity, recurrent or tension pneumothorax, limited decision-making, chronic lung disease, HIV or Marfan syndrome	1.3-mm angio intravenous catheter, a 3-way valve, and 50-mL syringe	Total patients: 25 Success: 17 (68%) **	Hospital duration: 2.4 ± 2.6 days**	
Yamagami *et al.*, 2006[16]	Prospective cohort study	Inclusion: Post CT-guided biopsy with pneumothorax not considered to be small (≥7 slices on post-biopsy CT) irrespective of symptoms Exclusion: N/A	18-G IV catheter, a 3-way stopcock, and 50-mL syringe under real-time CT fluoroscopy guidance	Total patients: 72 Success: 61 (84.7%)	Hospital duration: - Complete resolution: 1.9 ± 2.0 (1 day, 0-7) days - Partial resolved: 4.1 ± 2.4 (3, 0-8) days	

G: gauge, IV: intravenous, N/A: not applicable

*Success was defined as aspiration only without subsequent rescue method such as tube thoracostomy.

**The study did not separate patients with pneumothorax of different etiologies (included both spontaneous pneumothorax and traumatic pneumothorax).

	Study design	Enrolment criteria	Method of aspiration	Patient number and success rate*, n (%)	Procedure time and hospital duration	Pain, costs, and complications
Faruqi *et al.*, 2004[17]	Prospective cohort study	Inclusion: Size of pneumothorax ≥15% of hemithorax or symptomatic Exclusion: Very sick patient or tension pneumothorax	18-G IV catheter, a 3-way stopcock, and 50-mL syringe	Total patients: 12 Success: 11 (91.7%)	Hospital duration: - Aspiration only: 1.6 days - Aspiration failed followed with intercostal tube: 10 days - Direct with intercostal tube: 8.2 days	Pain: VAS 1.6 (aspiration) VAS 4.2 (failed with intercostal tube) VAS 4.0 (intercostal tube) Cost: Simple aspiration: 90 IRP Direct intercostal tube: 300 IRP
Yamagami *et al.*, 2002[24]	Prospective cohort study	Inclusion: Post CT-guided biopsy with pneumothorax not considered to be small (≥7 slices on post-biopsy CT) irrespective of symptoms Exclusion: N/A	18-G IV catheter, a 3-way stopcock, and 50-mL syringe under real-time CT fluoroscopy guidance	Total patients: 20 Success: 18 (90%)	Hospital duration: 3.60 ± 2.78 (range, 0-9; median, 3) days	
Yankelevitz *et al.*, 1996[23]	Prospective cohort study	Inclusion: Post CT-guided biopsy with large size pneumothorax (visually estimated >30% on CT) Exclusion: N/A	18-G 5-cm IV catheter, a 3-way stopcock, and 50-mL syringe	Total patient:17 Success: 12 (70.6%)	Procedure duration: 10-15min	Complication: nil

G: gauge, IV: intravenous, N/A: not applicable

*Success was defined as aspiration only without subsequent rescue method such as tube thoracostomy.

**The study did not separate patients with pneumothorax of different etiologies (included both spontaneous pneumothorax and traumatic pneumothorax).

	Study design	Enrolment criteria	Method of aspiration	Patient number and success rate*, n (%)	Procedure time and hospital duration	Pain, costs, and complications
Markos *et al.*, 1990[21]	Prospective cohort study	Inclusion: Symptomatic pneumothorax (dyspnea, chest pain) visually ≥ 20% of hemithorax by PA CXR Exclusion: Severe respiratory distress, simultaneous bilateral pneumothoraxes, post pneumonectomy	16-G IV catheter, a 3-way stopcock, and 60-mL syringe	Total patients: 12 Success: 8 (67%)	Hospital duration: success: 1.13 ± 0.35 days failed: 3.50 ± 0.71 days	Cost: No exact amount but mentioning that the cost of simple aspiration is 1/10th of that of the large intercostal catheter Complication: local subcutaneous emphysema (6 patients) and mild vasovagal reaction (2 patients)
Delius *et al.*, 1989[11]	Prospective cohort study	Inclusion: Age ≥16 years, simple uncomplicated pneumothorax on chest X-ray Exclusion: Pleural effusion, hemothorax, multiple traumas, respiratory distress, hemodynamic instability	8-F radiopaque polytetrafluoroethylene (Teflon) catheter with a 3-way stopcock, and a 50-mL syringe	Total patients:79 Success: 59 (74.7%)	Hospital duration: N/A (Discharge after 6 hours)	Cost: catheter aspiration: 868 USD Heimlich valve: 2884 USD Heimlich valve plus suction: 3028 USD Chest tube: 6402 USD Complication: 1 hemothorax; 2 retained sheared catheter tips

G: gauge, IV: intravenous, N/A: not applicable

*Success was defined as aspiration only without subsequent rescue method such as tube thoracostomy.

**The study did not separate patients with pneumothorax of different etiologies (included both spontaneous pneumothorax and traumatic pneumothorax).

	Study design	Enrolment criteria	Method of aspiration	Patient number and success rate*, n (%)	Procedure time and hospital duration	Pain, costs, and complications
Talbot *et al.*, 1986[10]	Prospective cohort study	Inclusion: Age ≥16 years, simple uncomplicated pneumothorax on chest X-ray Exclusion: Cardiopulmonary instability, presence of hemothorax, hydrothorax, complex pulmonary disease	16-G IV catheter, a 3-way stopcock, and a 50-mL syringe	Total patients: 57 Success: 46 (80.7%)	Hospital duration: 5.8 (4-10) days	
Obeid *et al.*, 1985[12]	Prospective cohort study	Inclusion: Simple traumatic pneumothorax Exclusion: Hemodynamic unstable; clinically important injuries; hemothorax; hydrothorax; pulmonary disease; respiratory distress	16-G IV catheter, a 3-way stopcock and a 50-mL syringe	Total patients:17 Success at 1st attempt: 14/17 (82.4%) Success after 2nd attempt: 16/17 (94.1%)	Hospital duration: N/A (no hospitalization)	Cost: Aspiration: 310 USD Chest tube: 3,030 USD
G: gauge, IV: intravenous, N/A: not applicable						
*Success was defined as aspiration only without subsequent rescue method such as tube thoracostomy.						
**The study did not separate patients with pneumothorax of different etiologies (included both spontaneous pneumothorax and traumatic pneumothorax).						

In this study, discomfort measurement before, during, and after the procedure was recorded as a very low pain score. Most patients reported no pain, except for minimal discomfort while receiving the local anesthesia injection before catheter placement. A similar result was reported by Faruqi *et al.*, and the mean pain scores for simple aspiration and intercostal tube drainage were 1.6 and 4.0 respectively[17]. Moreover, the lack of indwelling catheter not only alleviated the irritable sensation that occurs owning to the presence of a foreign body object inside the body, which enabled patients to mobilize freely without limitation or fear of tube dislodgement, but also reduced the clinical burden of tube care on the nursing stuff and the medical costs[11,21]. Finally, no complication occurred in patients who underwent vacuum bottle plus non-tunneled catheter drainage in this study. Hence, we are confident that vacuum bottle plus non-tunneled catheter drainage, similar to previously reported manual simple air aspiration, is a safe and efficient procedure (Table 3)[10–12,16,17,20–24].

Unlike other previous studies, we also evaluated the clinical outcomes of the patients in the oxygenation only group and found that the event-free duration differed dramatically with the size of pneumothorax, considering 10% as the cut-off point. As the size of pneumothorax between 10% and 20% remained a gray area for either intervention or watchful waiting, we suggest that initial management should entail simple aspiration by a chest specialist, because a successful air drainage reduced the duration of hospital stay and medical costs, especially in patients with pneumothorax size of 15–20%.

This study has several limitations. First, we did not perform a head-to-head comparison between catheter plus vacuum bottle-assisted air drainage and manual needle aspiration. Besides, a retrospective comparison may preclude validation of the data presented. A direct prospective randomized controlled trial may be required to overcome the limitation in the future. Second, this study was conducted in a single center and with predominantly CT-guided biopsy induced pneumothorax, which may prevent generalization of the findings. Third, there is no universal method adopted by different studies and guidelines. In addition, all these measurements are based on chest radiography, a 2-dimensional imaging modality, which may show disagreement on size of pneumothorax from each other. Further, the pleural line did not appear smooth in most patients, which could render the calculation incorrect for formulas that use only one parameter, such as Light's formula or the interpleural distance at the hilum level considered by the British Thorax Society. This study adopted Rhea's criteria, as we consider 3 sites of distance measurement for calculation, which suits most cases of lung collapse with varying shapes of pleural line. More accurate evaluation methods such as CT imaging may be considered and a universal consensus may be required, especially in asymptomatic patients with subjective large pneumothorax. Finally, the results of the current study can be applied only in patients with stable vital signs and not in those receiving positive mechanical ventilation.

Conclusion

Through this prospective cohort study, we proved that vacuum bottle plus non-tunneled catheter air drainage is a safe and effective air drainage method that is associated with a short hospital stay, less patient discomfort, and reduced medical costs; moreover, this procedure could help determine the necessity of further tube thoracostomy. It is recommended for stable patients with symptomatic post-procedural pneumothorax or pneumothorax size larger than 15%, as measured by Rhea's method.

Declarations

Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Author contributions:

S.Y.C. and Y.W.K. participated in data collection and analysis. Y.W.K. and H.D.W. provided materials and technical support. S.Y.C. and Y.W.K. contributed to the conception and design of the study and wrote the manuscript. S.Y.C., Y.W.K., C.C.H., H.D.W., H.C.W. participated in critical discussion of research design and thorough review of the manuscript.

Competing Interests Statement:

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Tables

Table 1. Baseline Demographics of the Study Subjects

	Total	Intervention group	Control group	p value
	(n=52)	(n=21)	(n=31)	
Age, year	66.5(61,70)	64(62,69)	68(59,73)	0.582
Male	27(51.9%)	10(47.6%)	17(54.8%)	0.609
Height, cm	160(152.8,166.8)	158.3(152.6,164.7)	162(152.8,167.3)	0.244
Weight, kg	61.5(55.2,68.7)	58.4(47.6,64.8)	63.1(57.1,71.6)	0.043
BMI	23.3(21.1,26.3)	22.4(20.6,23.7)	24.6(21.4,27.0)	0.061
Current smoker	18(34.6%)	7(33.3%)	11(35.5%)	1
Procedure				
CT-guided biopsy	40	14	26	0.518
Echo guided biopsy	2	1	1	
Bronchoscopic biopsy	4	2	2	
Thoracentesis	6	4	2	
Underlying disease				
Lung cancer	41	17	24	0.501
COPD	8	2	6	
Asthma	3	0	3	
Bronchiectasis	1	0	1	
Previous pneumothorax	1	1	0	

Data are presented as n (%) or median (interquartile range).

COPD: chronic obstructive pulmonary disease; control group: oxygenation only group.

Table 2. Patient Outcomes

	Intervention group	Control group	p value
	(n=21)	(n=31)	
Amount (%)	19.6(16,24)	8.8(6.2,13.2)	<0.05
Right site	17	18	0.084
Outcome			
Lung expansion	15 (71.4%)	30 (96.8%)	0.013
Pigtail rescue	6 (28.6%)	1	

Data are presented as n (%) or median (interquartile range).

control group: oxygenation only group

Table 3. Comparison of Studies Employing Simple Air Aspiration in Patients with Iatrogenic or Traumatic Pneumothoraxes

	Study design	Enrolment criteria	Method of aspiration	Patient number and success rate*, n (%)	Procedure time and hospital duration	Pain, costs, and complications
Chen *et al.*, 2021	Prospective cohort study	Inclusion: Radiographic evidence of pleural line after lung biopsy and the size of pneumothorax ≥ 15% (Rhea's criteria) Exclusion: Age < 20 years, bleeding tendency, and hemodynamic instability	16G IV catheter, a 3-way stopcock, drainage set, and vacuum bottle	Total patients: 21 Success: 15 (71.4%)	Procedure time: median 90 (IQR 60-180) seconds Hospital duration: Median 2 (IQR 1-4) days	Pain: - before: median 1 (IQR 0-1) - during: median 1 (IQR 0-1) - after: median 0 (IQR 0-1) Cost: Vacuum bottle plus catheter aspiration: 49 USD Pigtail drainage: 136 USD Complications: nil
Domokos *et al.*, 2020[20]	Retrospective cohort study	Inclusion: Pneumothorax with visible rim ≥ 2 cm between the lung margin and the chest wall at the level of the hilum Exclusion: N/A	16-G or 18-G over the needle cannula, a 3-way stopcock, and 50-mL syringe	Total patients:14 Success: 8 (57.1%)	Hospital duration: 2.0 (IQR 2.0-3.25) days	
Parlak *et al.*, 2012[22]	Prospective randomized controlled study	Inclusion: age 18-85 years, first symptomatic pneumothorax or asymptomatic with size ≥ 20% (Light's index) Exclusion: Pregnancy, severe comorbidity, recurrent or tension pneumothorax, limited decision-making, chronic lung disease, HIV or Marfan syndrome	1.3-mm angio intravenous catheter, a 3-way valve, and 50-mL syringe	Total patients: 25 Success: 17 (68%) **	Hospital duration: 2.4 ± 2.6 days**	
Yamagami *et al.*, 2006[16]	Prospective cohort study	Inclusion: Post CT-guided biopsy with	18-G IV catheter, a 3-way stopcock, and 50-mL syringe under real-	Total patients: 72	Hospital duration:	

		pneumothorax not considered to be small (≥7 slices on post-biopsy CT) irrespective of symptoms Exclusion: N/A	time CT fluoroscopy guidance	Success: 61 (84.7%)	• Complete resolution: 1.9 ± 2.0 (1 day, 0-7) days • Partial resolved: 4.1 ± 2.4 (3, 0-8) days	
Faruqi *et al.*, 2004[17]	Prospective cohort study	Inclusion: Size of pneumothorax ≥15% of hemithorax or symptomatic Exclusion: Very sick patient or tension pneumothorax	18-G IV catheter, a 3-way stopcock, and 50-mL syringe	Total patients: 12 Success: 11 (91.7%)	Hospital duration: • Aspiration only: 1.6 days • Aspiration failed followed with intercostal tube: 10 days • Direct with intercostal tube: 8.2 days	Pain: VAS 1.6 (aspiration) VAS 4.2 (failed with intercostal tube) VAS 4.0 (intercostal tube) Cost: Simple aspiration: 90 IRP Direct intercostal tube: 300 IRP
Yamagami *et al.*, 2002[24]	Prospective cohort study	Inclusion: Post CT-guided biopsy with pneumothorax not considered to be small (≥7 slices on post-biopsy CT) irrespective of symptoms Exclusion: N/A	18-G IV catheter, a 3-way stopcock, and 50-mL syringe under real-time CT fluoroscopy guidance	Total patients: 20 Success: 18 (90%)	Hospital duration: 3.60 ± 2.78 (range, 0-9; median, 3) days	
Yankelevitz *et al.*, 1996[23]	Prospective cohort study	Inclusion: Post CT-guided biopsy with large size pneumothorax (visually estimated >30% on CT) Exclusion: N/A	18-G 5-cm IV catheter, a 3-way stopcock, and 50-mL syringe	Total patient:17 Success: 12 (70.6%)	Procedure duration: 10-15min	Complication: nil
Markos *et al.*, 1990[21]	Prospective cohort study	Inclusion: Symptomatic pneumothorax (dyspnea, chest pain) visually ≥ 20% of hemithorax by PA CXR	16-G IV catheter, a 3-way stopcock, and 60-mL syringe	Total patients: 12 Success: 8 (67%)	Hospital duration: success: 1.13 ± 0.35 days failed: 3.50 ± 0.71 days	Cost: No exact amount but mentioning that the cost of simple aspiration is 1/10th of that of the large

		Exclusion: Severe respiratory distress, simultaneous bilateral pneumothoraxes, post pneumonectomy				intercostal catheter Complication: local subcutaneous emphysema (6 patients) and mild vasovagal reaction (2 patients)
Delius *et al.*, 1989[11]	Prospective cohort study	Inclusion: Age ≥16 years, simple uncomplicated pneumothorax on chest X-ray Exclusion: Pleural effusion, hemothorax, multiple traumas, respiratory distress, hemodynamic instability	8-F radiopaque polytetrafluoroethylene (Teflon) catheter with a 3-way stopcock, and a 50-mL syringe	Total patients:79 Success: 59 (74.7%)	Hospital duration: N/A (Discharge after 6 hours)	Cost: catheter aspiration: 868 USD Heimlich valve: 2884 USD Heimlich valve plus suction: 3028 USD Chest tube: 6402 USD Complication: 1 hemothorax; 2 retained sheared catheter tips
Talbot *et al.*, 1986[10]	Prospective cohort study	Inclusion: Age ≥16 years, simple uncomplicated pneumothorax on chest X-ray Exclusion: Cardiopulmonary instability, presence of hemothorax, hydrothorax, complex pulmonary disease	16-G IV catheter, a 3-way stopcock, and a 50-mL syringe	Total patients: 57 Success: 46 (80.7%)	Hospital duration: 5.8 (4-10) days	
Obeid *et al.*, 1985[12]	Prospective cohort study	Inclusion: Simple traumatic pneumothorax Exclusion: Hemodynamic unstable; clinically important injuries; hemothorax; hydrothorax; pulmonary disease; respiratory distress	16-G IV catheter, a 3-way stopcock and a 50-mL syringe	Total patients:17 Success at 1st attempt: 14/17 (82.4%) Success after 2nd attempt: 16/17 (94.1%)	Hospital duration: N/A (no hospitalization)	Cost: Aspiration: 310 USD Chest tube: 3,030 USD

G: gauge, IV: intravenous, N/A: not applicable

*Success was defined as aspiration only without subsequent rescue method such as tube thoracostomy.

**The study did not separate patients with pneumothorax of different etiologies (included both spontaneous pneumothorax and traumatic pneumothorax).

Figures

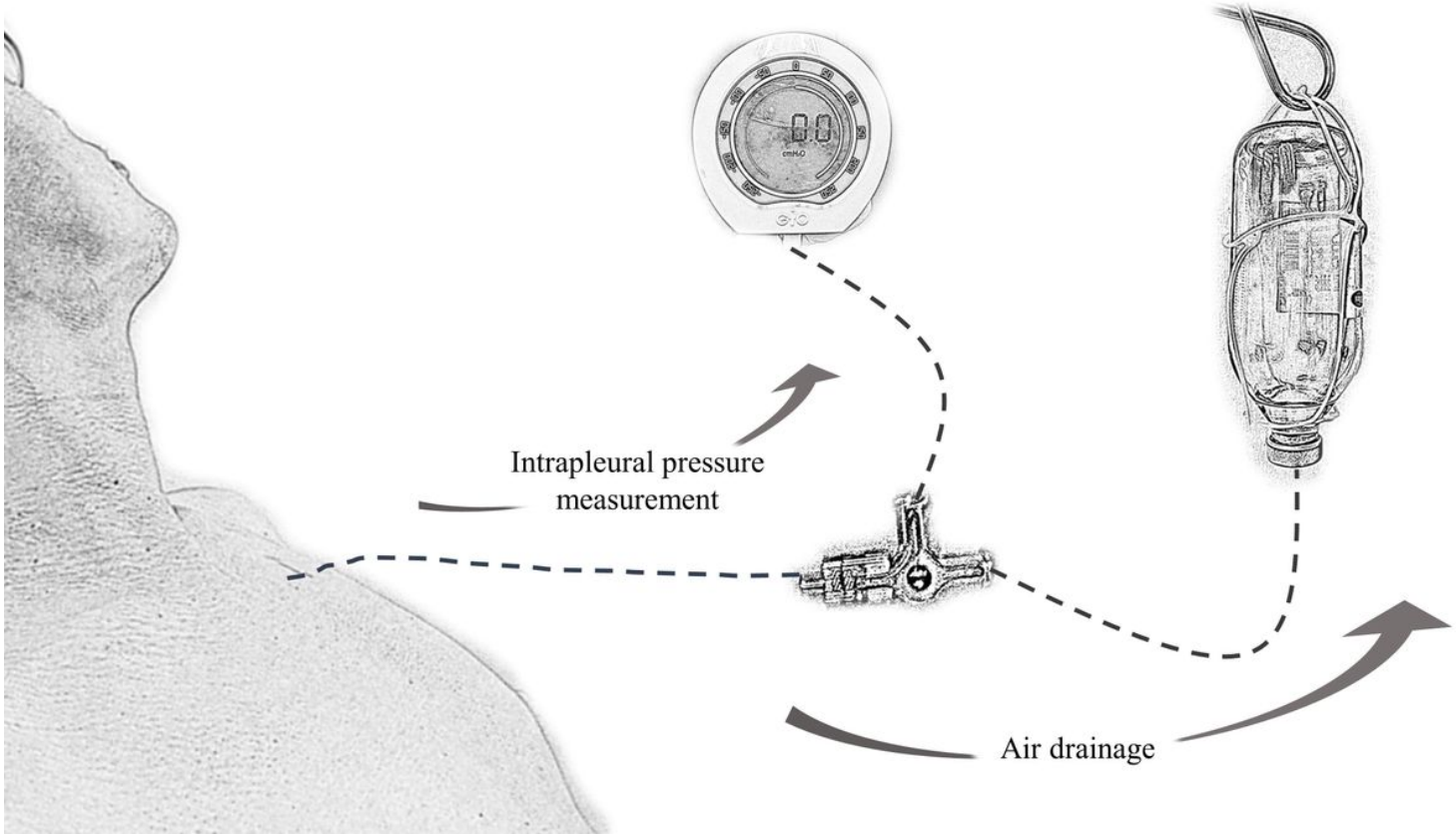

Figure 1

A schematic diagram of how vacuum bottle plus non-tunneled catheter air drainage and end-expiration intrapleural pressure were measured.

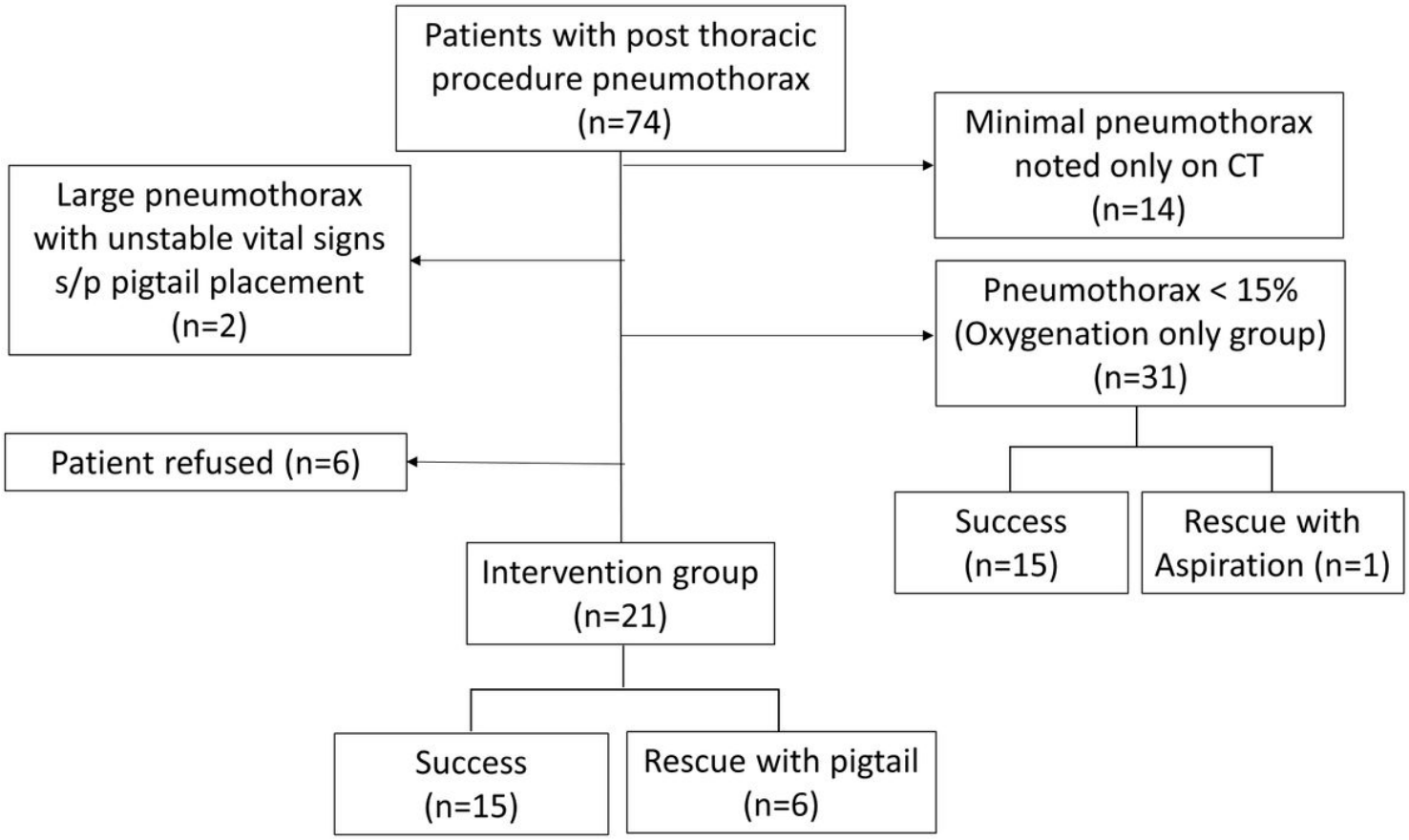

Figure 2

Flow chart of subject recruitment process for this study.

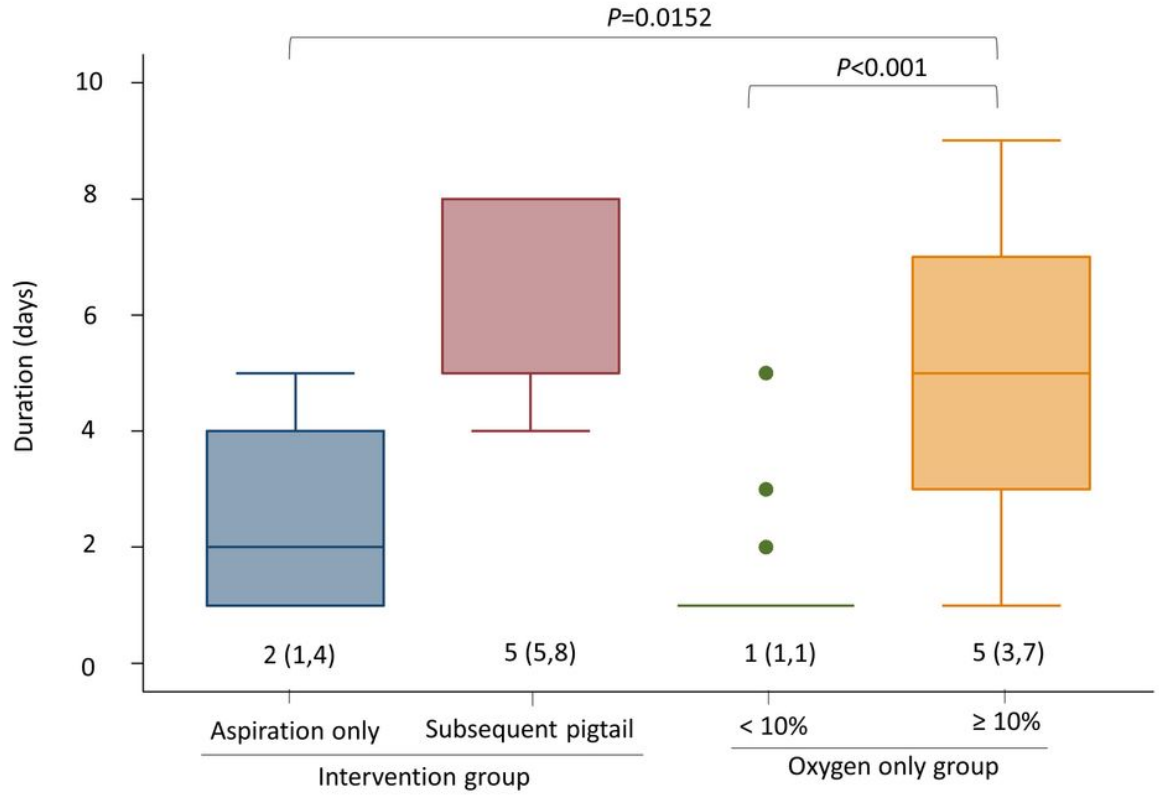

Figure 3

Box plots for subgroup comparison of time to event-free duration between the intervention group and oxygen only group. Median (interquartile range)

Supplementary Files

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- SupplementScientificReports20211022.pdf
- SupplementaryVideoS2VideoofAirdrainageScientificReports.mp4