Original Article

Effects of pleural drainage on oxygenation in critically ill patients

Masako Sakurai, iD Kentaro Morinaga, iD Keiichiro Shimoyama, Shiro Mishima, and Jun Oda iD

Department of Emergency and Critical Care Medicine, Tokyo Medical University, Tokyo, Japan

Aim: Pleural effusion is common among critically ill patients and associated with clinical consequences; however, the benefits of draining pleural effusion remain debatable. Thus, we aimed to investigate pleural drainage effectiveness by focusing on preprocedure patient status.

Methods: We retrospectively analyzed 22 patients with pleural effusion. Gas exchange, ventilator settings, vital signs, inflammatory response, and nutrition status were examined preprocedure and 24 h and 1 week postprocedure. Data were analyzed using the nonparametric test and discriminant analysis with receiver operating characteristic curves.

Results: The partial arterial oxygen pressure (PaO_2) to fraction of inspiratory oxygen (F_IO_2) (P/F) ratio at 24 h was higher postdrainage than predrainage (250 ± 87 versus 196 ± 84, $P < 0.05$); however, no significant difference between the P/F ratio predrainage and 1 week postdrainage was noted. Patients were classified into effective and ineffective groups according to a 110% increase in the P/F ratio 1 week postdrainage compared with predrainage. The predrainage P/F ratio was lower in the effective group than in the ineffective group (165 ± 91 versus 217 ± 74, $P < 0.05$). Discriminant analysis showed the area under the receiver operating characteristic curve was 0.72; the cut-off value of the predrainage P/F ratio (divided into effective and ineffective groups) was 174.

Conclusions: Pleural drainage could be effective in patients who have lower preprocedure P/F ratios.

Key words: Drainage, intensive care, pleural effusion, respiratory failure, thoracentesis

INTRODUCTION

PLEURAL EFFUSION IS frequently observed in critically ill patients and is associated with various underlying diseases or conditions, such as pneumonia, lung edema, hypoalbuminemia, and fluid therapy.[1] It affects respiratory function and the duration of ventilator support.[2] Thoracentesis and pleural drainage is a common procedure for the removal of the effusion and re-expansion of the collapsed lung. However, the benefits of draining pleural effusion are controversial. Some studies focusing on respiratory function showed that pleural drainage improved gas exchange;[3–5] however, in others, it did not.[6,7]

The diversity in patient backgrounds, underlying diseases, and properties of pleural effusion, such as exudative or transudative, can be considered as the cause of arguments for and against pleural drainage. Therefore, we need to determine the status of patients before undertaking thoracentesis to predict whether pleural drainage would be effective. To address this matter, we retrospectively studied the effects of pleural drainage on the oxygenation status of patients under mechanical ventilator support.

METHODS

Participants

THIS RETROSPECTIVE, SINGLE-CENTER observational study included approximately 2,700 critically ill adult patients who visited the hospital and were treated in the emergency room (ER). Approximately 1,500 of them

were annually admitted into the intensive care unit (ICU) of our department.

Consecutive patients under ventilator support with pleural drainage for effusion were enrolled in this study. The study included patients aged ≥15 years who had pleural effusion and were admitted to the critical care center. The exclusion criteria included age <15 years and the presence of pneumothorax and chest trauma.

Our department is a tertiary emergency care center comprising an ER and a mixed ICU on the hospital's ground floor. The ER accommodates patients transported by an ambulance, which is dispatched by the Tokyo Fire Department. The ICU has a capacity of 20 beds for outpatients. The hospital has another ICU that caters to inpatients, such as those undergoing elective surgery. Approximately 1,500 patients are treated annually at the department (data from 2012).

Intervention

Pleural drainage was carried out using either the open technique or the Seldinger method. The choice of procedure was at the discretion of the patient's attending physician. A chest tube (Argyle Trocar Catheter, 20–28 Fr; Covidien Japan) was used for carrying out the open technique. The tube was attached to a closed drainage system with a continuous suction pressure of -10 cm H_2O. In the Seldinger method, an 8-Fr locking pigtail catheter (Argyle Aspiration Seldinger Kit; Covidien Japan) was installed, and pleural effusion was drawn manually using a 20-mL syringe. The chest tube and pigtail catheter remained in place until the amount of removed fluid reached 100 mL over 24 h.

Measurements

We reviewed the following information using the hospital charts and radiographs of the patients: demographics, clinical characteristics, ventilator settings (fraction of inspiratory oxygen [F_IO_2], mode of operation), laboratory findings including blood gas analysis (pH, partial arterial oxygen pressure [PaO_2], partial arterial oxygen pressure [$PaCO_2$]), Acute Physiology and Chronic Health Evaluation II score,[8] and Sequential Organ Failure Assessment score[9] prior to the pleural drainage. The amount of removed fluid, duration of tube placement, and procedure-related complications, such as pneumothorax, hemothorax, and empyema, were also recorded. Seven days after initiating the drainage, blood gas analysis was repeated. We evaluated oxygenation with the oxygenation index: PaO_2 divided by F_IO_2, as the P/F ratio, before and 7 days postdrainage to determine the oxygenation ability of the lungs. Patients with a P/F ratio increase of >110% 7 days postdrainage were categorized into the "effective" group. The primary outcome of the study was to examine the effects of pleural drainage on the P/F ratio. Furthermore, the contributing factors to lung oxygenation were compared between the effective and ineffective groups.

Statistical analysis

Continuous variables are expressed as mean ± standard deviation. Using a paired Student's *t*-test with Bonferroni correction, comparisons between preprocedure and postprocedure variables were assessed. We undertook non-parametric analyses to compare the clinical characteristics and contributing factors between the effective and ineffective groups. Depending on the data type, a χ^2-test or Mann–Whitney *U*-test was applied. A two-sided *P*-value of <0.05 was considered significant. To validate the effectiveness of pleural drainage, we built receiver operating characteristic (ROC) curves using each of the contributing factors based on a non-parametric technique[10] and calculated the area under the curve (AUC). The accepted statistical rule of thumb is that a test with an AUC of >0.7 provides acceptable discriminative ability.[11]

RESULTS

A TOTAL OF 22 patients were enrolled. Table 1 shows their characteristics. The mean age of the patients was 78 years. In this study, the most common cause of ICU admission was pneumonia. The P/F ratio 1 day postdrainage initiation was significantly higher than that predrainage (231 ± 85 versus 194 ± 83, *P* = 0.044; Table 2). However, this improvement in lung oxygenation ability was not observed 7 days postdrainage. The other respiratory variables, such as $PaCO_2$ and respiratory rate, were not significantly different pre- and postdrainage. As the improvement effectuated by pleural drainage did not last for a week, we divided the subjects into two groups. Patients who had >110% P/F ratio on day 7 after drainage were defined as "effective," whereas those who had <110% P/F ratio were defined as "ineffective." We checked the standard error of the P/F ratio predrainage (average P/F ratio before drainage, 194; standard error, 18.2). The standard error of the P/F ratio predrainage was <10% of its average, and we set the divided point to 110% of the P/F ratio postdrainage, in comparison to that predrainage. The P/F ratio 7 days postdrainage initiation was significantly higher in the effective group than in the ineffective group (Table 3, Fig. 1). In the comparisons between the effective and ineffective groups, the P/F ratio predrainage is just one variable, bearing a significant difference among the evaluated parameters. The incidence and

Table 1. Demographics and clinical characteristics of critically ill patients who underwent pleural drainage (*n* = 22)

Demographics	Data
Age, years	78 ± 10
Sex, female (male)	12 (10)
Admission diagnosis	
Pneumonia	12
GI disease	9
Stroke	3
PCAS	3
Others	3

Data are reported as mean ± standard deviation or number.
GI, gastrointestinal tract; PCAS, postcardiac arrest syndrome.

severity of complications related to the procedure did not differ between the groups (data not shown). Thus, the ROC curve was constructed for testing the ability to predict the utility of pleural drainage using the P/F ratio predrainage (Fig. 1). The area under the ROC curve, which detects a P/F ratio increase of >110% compared with that predrainage, was 0.72 (Fig. 2). The cut-off value of the P/F ratio predrainage was 174 (Fig. 2).

DISCUSSION

IN NORMAL CONDITIONS, the pleural space contains little fluid, probably <20 mL. However, intensive care patients commonly develop pleural effusion, being evident in 50–60% of patients.[12] The benefit of pleural drainage in mechanically ventilated patients is controversial, with conflicting data concerning its effects on oxygenation. In the study by Walden *et al.*[3] on 10 mechanically ventilated patients, it was shown that the P/F ratio increased after pleural drainage (from 169 ± 56 to 238 ± 73, $P < 0.05$). The oxygenation improvement was maintained for a period of 48 h. Talmor *et al.*[5] reported that 19 of 199 consecutive

patients with acute respiratory failure required tube thoracostomy. The P/F ratio remained statistically higher 24 h postdrainage (from 151 ± 13 to 245 ± 29, $P < 0.01$).[5] A similar result was found in the study by Roch *et al.*[4] They undertook pleural drainage in 44 patients receiving mechanical ventilation with a predefined indication (hypoxemia or weaning failure).[4] In another study, 26 mechanically ventilated patients with heart failure and transudative effusions, who were undergoing therapeutic thoracentesis, were investigated.[13] The mean P/F ratio immediately increased after thoracentesis (from 243 ± 20 to 336 ± 18, $P < 0.001$). The changes in the P/F ratio after thoracentesis were inversely correlated with the pleural space elastance.[13]

In contrast, in the study by Doelken *et al.*,[14] there was no change in the oxygenation status of eight patients receiving mechanical ventilation with large pleural effusions. Thoracentesis resulted in significant reductions of the pleural liquid pressure and the work performed by the ventilator. However, these changes were not accompanied by meaningful alterations in gas exchange after drainage. Ahmed *et al.*[7] investigated the effect of pleural drainage on large effusions by prospectively studying 22 ventilated patients in the surgical ICU of a tertiary care center. The pulmonary capillary wedge pressure and central venous pressure decreased; however, the P/F ratio did not change significantly after drainage. Formenti *et al.*[15] studied combined therapy with recruitment maneuvers and pleural effusion drainage. They found that neither recruitment nor drainage improved the gas exchange. The inconsistent results on oxygenation improvement after pleural drainage could be due to diverse factors, such as underlying diseases, fluid properties (transudative or exudative), and ventilator settings, particularly positive end-expiratory pressure.

Even in studies that reported oxygenation improvement by pleural drainage, it was uncertain whether the positive effects influenced the clinical outcome. In fact, in this study, the P/F ratio increased on the day of postdrainage initiation; however, the improvement did not last until the seventh day.

Table 2. Comparison of respiratory variables before, 1 day after, and 7 days after pleural drainage

	Before drainage	Next day	7 days later
P/F ratio	194 ± 84	231 ± 85*	234 ± 86
PaCO₂ (Torr)	45.1 ± 12.5	43.2 ± 8.44	46.7 ± 11.3
Respiratory rate (breaths/min)	21.7 ± 4.5	21.6 ± 5.8	23.5 ± 6.2

Data are reported as mean ± standard deviation or number.
$PaCO_2$, partial arterial oxygen pressure; P/F, partial arterial oxygen pressure (PaO_2) divided by inspiratory oxygen (F_IO_2).
*$P < 0.05$ versus predrainage.

Table 3. Description factors compared between the "effective" and "ineffective" groups of critically ill patients who underwent pleural drainage

	Effective (*n* = 12)	Ineffective (*n* = 10)	*P*-value
Age, years	80.4 ± 10.7	75.9 ± 9.3	0.206
Predrainage P/F	165 ± 87	230 ± 63	0.047
WBC (/μL)	10.5 ± 4.8	9.3 ± 3.4	0.832
CRP (mg/dL)	13.6 ± 8.6	14.1 ± 6.0	0.198
SOFA	9.8 ± 3.5	9.9 ± 2.6	0.946
APACHE II	18.3 ± 6.5	17.9 ± 5.7	0.166
7 days postdrainage P/F	271 ± 87	189 ± 59	0.025
Fluid amount (mL)			
First day	801 ± 258	922 ± 231	0.218
7 days total	2207 ± 1310	3430 ± 2351	0.291
ICU stay (days)	36.7 ± 28.1	30.4 ± 13.9	0.973
LOS (days)	37.9 ± 28.6	35.0 ± 19.4	0.741

Patients in the effective group were discriminated from the ones in the ineffective group using the partial arterial oxygen pressure (PaO_2) divided by inspiratory oxygen (F_IO_2) (P/F) ratio 7 days after drainage, which increased ≥110% from that before drainage.
Data are reported as mean ± standard deviation or number.
APACHE II, Acute Physiology and Chronic Health Evaluation II; CRP, C-reactive protein; ICU, intensive care unit; LOS, length of stay; SOFA, Sequential Organ Failure Assessment; WBC, white blood cells.
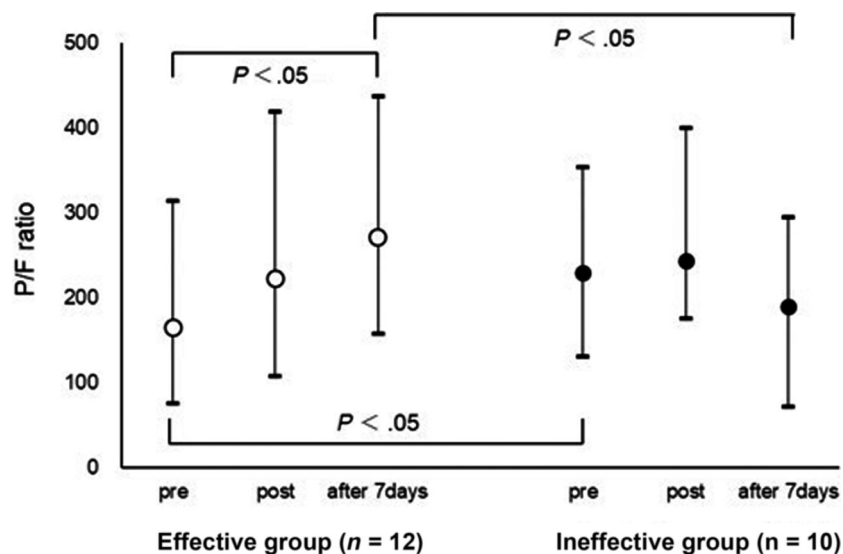
Fig. 1. Effect of pleural drainage in the effective and ineffective groups of patients, classified according to a 110% increase in the ratio of partial arterial oxygen pressure (PaO_2) to inspiratory oxygen (F_IO_2) (P/F) 1 week postdrainage compared with predrainage.

Therefore, we need to identify variables for the prediction of sustained improvements by pleural drainage. The drainage volume could be a good candidate for estimating favorable outcomes. Roch *et al.*[4] reported that the P/F ratio significantly increased after chest drainage in patients with collected volumes of >500 mL.[4] However, in another study, there was no correlation between the volume of fluid removed and the P/F ratio postdrainage.[5] Thus, we classified the subjects into two groups according to the P/F ratio increase at 1 week postdrainage initiation to compare the
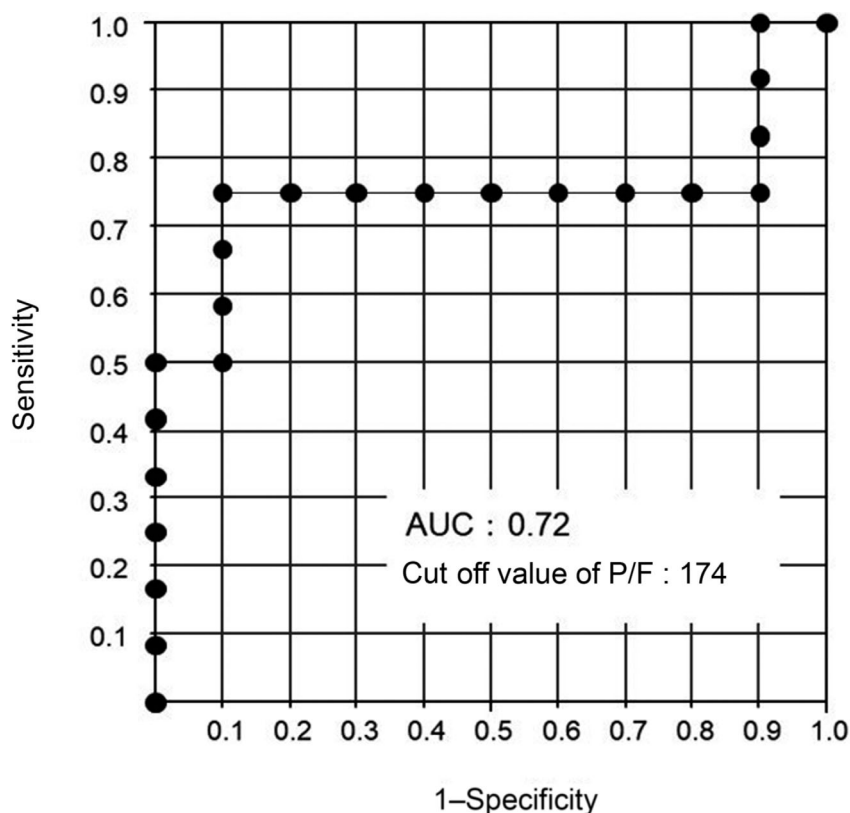
Fig. 2. Receiver operating characteristic curve describing the ability of the ratio of partial arterial oxygen pressure (PaO_2) to inspiratory oxygen (F_IO_2) (P/F) predrainage to detect a P/F ratio increase of $\geq$110% 7 days after drainage. AUC, area under the curve.

explanatory variables. The fluid volumes were not different between the effective and ineffective groups on both the first and the seventh day postdrainage. We found that the P/F ratio predrainage was only one variable, having a significant difference between the effective and ineffective groups. The cut-off value was 174, calculated using the ROC curve (Fig. 2). Thus, we suggest that if the P/F ratio is less than the value of that of a patient who had pleural effusion, pleural drainage will result in sustainable improvements in oxygenation under mechanical ventilation.

The oxygenation improvement by pleural effusion drainage was more effective in the low P/F ratio group. The lungs of patients with severe respiratory failure often have low compliance, and the alveoli are more likely to collapse than healthy lungs.[16,17] Therefore, the group with low P/F ratio was more likely to obtain improved oxygenation because the alveoli re-inflated and the shunt ratio was reduced by undertaking pleural effusion drainage. The oxygenation improvement was observed the next day. This is not a characteristic of improving lung parenchyma disorders,

such as diffusion disorders, but a characteristic of reduced shunt ratio. We considered that the mechanism of improvement in oxygenation by pleural effusion drainage was a decrease in shunt rate.

This study has several limitations. First, this was a retrospective, non-randomized, and single-center study. Therefore, the indication and timing of therapeutic thoracentesis and pleural drainage depended on the discretion of the patient's attending physician. Second, the property of the pleural fluid, either exudative or transudative, was not evaluated because of a gap in the examined data. Finally, some variables and outcomes related to ventilator support, particularly the positive end-expiratory pressure during the study period, and ventilator-free days were not analyzed.

CONCLUSIONS

WE SHOWED THAT the improvement in oxygenation by pleural drainage was sustained 1 week after thoracentesis among patients who had lower P/F ratios. The P/F

ratio can be used by practitioners as a predictor in making decisions concerning the indication and timing of pleural effusion drainage.

DISCLOSURE

Approval of the research protocol: This study was approved by the Institutional Review Board of Tokyo Medical University (IRB no. 2389).

Informed consent: All participants provided informed consent.

Registry and the registration no. of the study/trial: N/A.

Animal studies: N/A.

Conflict of interest: None.

REFERENCES

1 Maslove DM, Chen BTM, Wang H, Kuschner WG. The diagnosis and management of pleural effusions in the ICU. J. Intensive Care Med. 2013; 28: 24–36.

2 Brunelli A, Beretta E, Cassivi SD *et al*. Consensus definitions to promote an evidence-based approach to management of the pleural space. A collaborative proposal by ESTS, AATS, STS, and GTSC. Eur. J. Cardiothorac. Surg. 2011;40:291–7.

3 Walden AP, Garrard CS, Salmon J. Sustained effects of thoracocentesis on oxygenation in mechanically ventilated patients. Respirology 2010; 15: 986–92.

4 Roch A, Bojan M, Michelet P *et al*. Usefulness of ultrasonography in predicting pleural effusions > 500 mL in patients receiving mechanical ventilation. Chest 2005; 127: 224–32.

5 Talmor M, Hydo L, Gershenwald JG, Barie PS. Beneficial effects of chest tube drainage of pleural effusion in acute respiratory failure refractory to positive end-expiratory pressure ventilation. Surgery 1998; 123: 137–43.

6 Chiumello D, Marino A, Cressoni M *et al*. Pleural effusion in patients with acute lung injury: a CT scan study. Crit Care Med 2013; 41: 935–44.

7 Ahmed SH, Ouzounian SP, DiRusso S, Sullivan T, Savino J, Del Guercio L. Hemodynamic and pulmonary changes after drainage of significant pleural effusions in critically ills, mechanically ventilated surgical patients. J. Trauma 2004; 57: 1184–8.

8 Knaus WA, Draper EA, Wagner DP, Zimmerman JE. APACHE II: a severity of disease classification system. Crit. Care Med. 1985; 13: 818–29.

9 Vincent JL, Moreno R, Tanaka J *et al*. The SOFA (sepsis-related organ failure assessment) score to describe organ dysfunction/failure. Intensive Care Med. 1996; 22: 707–10.

10 DeLong ER, DeLong DM, Clarke-Pearson DL. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. Biometrics 1988; 44: 837–45.

11 Hosmer DW, Lemeshow S. Multiple logistic regression. In: Shewhart WA, Wilks SS (eds). Applied logistic regression. New York: John Wiley & Sons, Inc., 2000; 31–46.

12 Walden AP, Jones QC, Matsa R, Wise MP. Pleural effusions on the intensive care unit; hidden morbidity with therapeutic potential. Respirology 2013; 18: 246–54.

13 Chen WL, Chung CL, Hsiao SH, Chang SC. Pleural space elastance and changes in oxygenation after therapeutic thoracentesis in ventilated patients with heart failure and transudative pleural effusions. Respirology 2010; 15: 1001–8.

14 Doelken P, Abreu R, Sahn SA, Mayo PH. Effect of thoracentesis on respiratory mechanics and gas exchange in the patient receiving mechanical ventilation. Chest 2006; 130: 1354–61.

15 Formenti P, Umbrello M, Piva IR *et al*. Drainage of pleural effusion in mechanically ventilated patients: time to measure chest wall compliance? J. Crit. Care 2014; 29: 808–13.

16 Perlman CE, Lederer DJ, Bhattacharya J. Micromechanics of Alveolar Edema. Am. J. Respir. Cell Mol. Biol. 2011; 44: 34–9.

17 Leonenko Zoya, Gill Simardeep, Baoukina Svetlana *et al*. An Elevated Level of Cholesterol Impairs Self-Assembly of Pulmonary Surfactant into a Functional Film. Biophys. J. 2007; 93: 674–683.