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original Article

B-line scores and their correlation with the ratio of arterial partial pressure of oxygen to fractional inspired oxygen (PaO_2/FiO_2) and fluid balance in post-operative cardiac surgery patients

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Abstract

Objective: Fluids are administered to optimize hemodynamics during off-pump coronary artery bypass grafting (CABG), which may lead to a positive fluid balance and increased lung water, lung congestion, hypoxemia, prolonged mechanical ventilation, and longer hospital stays. Lung ultrasound can assess extravascular lung water and help titrate diuretics and fluids, thus preventing hypoxemia. The primary objective of this study was to study the correlation between B-line scores measured by lung ultrasound and the PaO_2/FiO_2 ratio (the ratio of arterial partial pressure of oxygen to fractional inspired oxygen) after off-pump CABG.

Methods: Forty off-pump CABG patients were included in this prospective observational study in a tertiary care center from 2022 to 2023. The correlation coefficient from an earlier study was used and a sample size of 9 was calculated. Random sampling technique was used. A four-sector lung ultrasound was utilized for B-line scoring. B-line scores and PaO_2/FiO_2 ratios were recorded at three time points: before the surgery commenced and at 24 and 48 hours post-operation. The fluid balance was calculated at 24 and 48 hours post-operation. Pearson correlation coefficient was used to evaluate the correlation between B-line scores and fluid balance with oxygenation, and its significance was assessed through a linear regression test.

Results: The PaO_2/FiO_2 ratio and B-line scores exhibited a statistically significant moderate negative correlation at 24 hours post-surgery ($r=-0.44$; SD = -0.66, 95% CI = -0.66, -0.15; $P=0.004$) and a B-line score exceeding 8 was associated with the lowest PaO_2/FiO_2 ratio. However, fluid balance and PaO_2/FiO_2 ratios revealed no correlation at 24 or 48 hours post-surgery. Additionally, fluid balance and B-line scores demonstrated a moderate positive correlation after 48 hours but no correlation at 24 hours post-surgery.

Conclusion: B-line scores always negatively correlated with PaO_2/FiO_2 ratios, and scores greater than eight corresponded to the lowest ratio.

Keywords: Coronary artery bypass, Lung ultrasound, Extravascular lung water, Fluid therapy, Hypoxia, Diuretics, Partial pressure

Introduction

Lung congestion during the post-operative period after cardiac surgery can affect oxygenation (1). The level of extravascular lung water contributes to pulmonary congestion, deoxygenation and pulmonary edema (2). Lung congestion was traditionally measured using chest radiograph scores and clinical judgements. Lung ultrasound (LUS) B-line scores can predict extravascular lung water with good sensitivity much before the clinical manifestation of congestion appears (3).

Pulmonary congestion is associated with increased mortality, especially after cardiac surgery. Hence, surgical units target a negative fluid balance using fluid restriction and diuretics (4). While lung ultrasound is an effective tool for evaluating extravascular lung water, many cardiac surgical units continue to rely on the net daily fluid balance and chest radiographs to determine daily fluid intake and diuresis (4,5). This is based on studies showing that increased lung water is associated with positive fluid balance. However, most of these were done in non-cardiac patients with no comorbidities (5). In cardiac surgery patients, extravascular lung water is not solely determined by fluid balance but also depends on a complex interplay of fluid volume, inflammatory responses, changes in vascular permeability, and cardiac function (6).

The primary objective of this study was to correlate B-line scoring with the PaO_2/FiO_2 ratio (the ratio of the partial pressure of oxygen in arterial blood to the fraction of inspired oxygen) following off-pump coronary artery bypass grafting (CABG) surgeries, assessed at 24 and 48 hours post-surgery. The secondary objectives included assessing the correlation between the net 24-hour fluid balance and lung ultrasound B-line score and the PaO_2/FiO_2 ratio measured at 24 and 48 hours post-surgery.

Methods

The present study is a prospective observational study conducted in a tertiary care center adult cardiovascular and thoracic surgery unit over 8 months (July 2022 to February 2023). Patients were included in the study after obtaining ethical committee approval from the institute (Amrita School of Medicine -ECASM-AIMS-2022-124) dated 1-07-2022). Written informed consent for participation and the use of their data for research and educational purposes were obtained from all patients.

The sample size was calculated based on the correlation coefficient (r) results between oxygenation and B-lines scoring post-surgery (r = -0.81) at 24 hours, as observed from existing literature, with 80% power and 95% confidence1. The formula used was:

$$n = Z_{1-\alpha/2}{}^{2}(1 - r^{2})^{2} / w^{2} + 1 + 6r^{2}$$

where n is the sample size, Z1 - α/2 is the standard normal table value for a given confidence level, r is the anticipated value of the correlation, and w is the precision or margin of error. The minimum required sample size was nine; however, we collected data from 40 patients, by random sampling, to compensate for dropout due to poor image windows and the risk of outliers, as ultrasound has high interobserver variability. We included all age groups of adult patients to improve generalizability.

Adult patients aged over 18 years who underwent off-pump CABG surgery with the placement of a Swan-Ganz catheter (pulmonary artery catheter) were included in the study. Those with pre-operative renal failure and conversion to on-pump were excluded. PaO_2 (partial pressure of oxygen in arterial blood) values were recorded from the arterial blood gas reports taken after anesthesia induction in the operating room and at 24 hours and 48 hours post-surgery by the attending nurse in the intensive care unit following the standard sampling technique as per the unit protocol. During the corresponding blood gas sampling, the inspired oxygen fraction was also documented by the nurse to calculate the PaO_2/FiO_2 ratios. Thus, the lowest PaO_2/FiO_2 ratio was obtained before surgery and at the end of 24 hours and 48 hours post-surgery. The study patients were typically extubated 6–8 hours post-surgery following the existing practice. The FiO_2 values were captured from the monitoring chart while the patient was on ventilation. After extubation, the fractional-inspired oxygen calculation was based on the flow rate of oxygen delivered via a face mask during the blood gas sampling ($FiO_2 = 0.21 + (0.03 \times$ Oxygen flow rate (L/min)).

The net daily fluid balance was assessed at 24 and 48 hours, corresponding to the B-line scores at those same time intervals. Lung ultrasound was performed by anesthesiologists with a minimum of 5 years of experience in lung ultrasonography. Observations of one anesthesiologist were confirmed by another equally trained anesthesiologist to reduce interobserver bias. The four-sector lung ultrasound (Figure 1)was utilized for B-line scoring at three time points before the surgery commenced and 24 and 48 hours post-surgery. The net fluid balance represents the difference between total fluid intake and total output. Total fluid intake was determined by summing crystalloids, colloids, blood products, and oral fluids administered over the past 24 hours. Total output was calculated by adding urine output, nasogastric aspirate, insensible loss, and mediastinal or chest drain output during the last 24 hours. Net fluid balance was computed as the cumulative difference between intake and output at 24 and 48 hours. Pulmonary capillary wedge pressure (PCWP) and the PaO_2/FiO_2 ratio were recorded before surgery as baseline, including the highest PCWP value.

Statistical analysis was performed using the Statistical Package for the Social Sciences version 21 (SPSS Inc., Chicago, Illinois, USA). All continuous variables, namely age, height, and weight, were described as means with standard deviation (SD). The correlation between fluid balance and the B-line score was assessed using the Pearson correlation coefficient. Its significance was evaluated through a linear regression test and mentioned along with its confidence interval (CI).

Results

The demographic data are summarized in Table 1. The study involved 40 patients, comprising five females and thirty-five males. The average age was 62.4 ± 9.4 years. The mean body surface area (BSA) was 1.7 ± 0.14 $m^{2,}$ and the

Table 1. Demographic variables

Demographic variables	Mean	SD
Age (y)	62.4	9.4
Height (cm)	163	8.356
Weight (kg)	68	8.719
BSA (kg/m²)	1.7	0.140
Gender	Female (*n*): 55, Male (*n*): 35	

BSA: Body surface area

average weight was 68 ± 8.71 kg. Regarding left ventricular (LV) function, ten patients exhibited good function, 27 had mild to moderate dysfunction, and the remaining three presented with severe dysfunction. Additionally, four patients were taking loop diuretics preoperatively.

At baseline, before the start of surgery, the B-line score and PaO_2/FiO_2 showed a non-significant negative correlation, as depicted in Table 2 and Figure 2. However, 24 hours after surgery, B-line scores demonstrated a statistically significant moderate negative correlation with PaO_2/FiO_2 ratio, as depicted in Table 2 and Figure 3 (r = -0.444; P = 0.004; SD of B-line score = 1.411; SD of PaO_2/FiO_2 ratio = 97.464; 95% CI = -0.702, -0.133). At 48 hours post-surgery, the r values were -0.287 (SD of PaO_2/FiO_2 = 83.336; B-line score = 1.488; CI = -0.55, 0.027) with corresponding P values of 0.073 (Table 2 and Figure 4). The lowest PaO_2/FiO_2 ratios were noted to be associated with a total B-line score of 8 or greater (Figure 2). The fluid balance and PaO_2/FiO_2 ratios at 24 and 48 hours revealed no significant correlation, with r = -0.21 (SD = -0.49; 95% CI = 0.11; P = 0.266) and -0.112 (SD = -0.41; 95% CI = 0.2; P = 0.412), respectively (Table 2). Additionally, fluid balance and B-line scores showed a weak positive correlation at 24 hours (r = 0.013; SD of fluid balance = 524.32; B-line score = 1.488; 95% CI = (-0.444, 0.32); P = 0.935) (Table 2). However, at 48 hours, a statistically significant moderate positive correlation was observed (r = 0.54; SD for fluid balance = 524; SD for B-line score = 1.48; 95% CI = (0.28, 0.73); P = 0.001). No significant correlation was found between B-line scores and PCWP before surgery or 24 or 48 hours post-surgery.

Table 2. Correlation of B-line score with PaO_2/FiO_2 ratio and fluid balance and correlation between PaO_2/FiO_2 ratio and fluid balance

Correlation between B-line score and PaO_2/FiO_2 ratio			
PaO_2/FiO_2 ratio	**B-line score**		
	***r* (SD p/f; SD B-line; 95% CI)**	***n***	***P* value**
Before surgery	-0.294 (73.18; 1.48; -0.662, -0.109)	40	0.066
24 h after surgery	-0.444 (97.464; 1.411; -0.702, -0.133)	40	0.004
48 h after surgery	-0.287 (83.336; 1.488; -0.55, 0.027)	40	0.073
Correlation between fluid balance and B-line scores			
B-line score	**Fluid balance**		
	***r* (SD fluid balance, SD B-line; 95% CI)**	***n***	***P* value**
24 h after surgery	0.013 (524.382; 1.488; -0.444, 0.32)	40	0.935
48 h after surgery	0.544 (524; 1.48; 0.28, 0.73)	40	0.001
Correlation between fluid balance and PaO_2/FiO_2 ratio			
Fluid balance	**PaO_2/FiO_2 ratio**		
	***r* (SD fluid balance, SD p/f; 95% CI)**	***n***	***P* value**
24 h after surgery	-0.21 (379.799; 83.336; -0.342, 0.315)	40	0.266
48 h after surgery	-0.112 (524.382; 83.336; -0.211, 0.457)	40	0.412

p/f or PaO_2/FiO_2: ratio of arterial partial pressure of oxygen and inspired fraction of oxygen.
The correlation coefficient with SD of the two variables and CI was calculated using Python software.

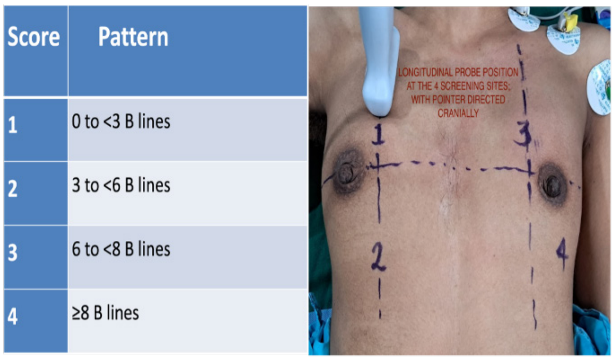

Figure 1. Position of the ultrasound probe and B-line score calculation in the 4-sector ultrasound protocol

Discussion

The study aimed to correlate B-line scoring with the PaO_2/FiO_2 ratio, fluid balance with the PaO_2/FiO_2 ratio and fluid balance with the B-line score following off-pump CABG

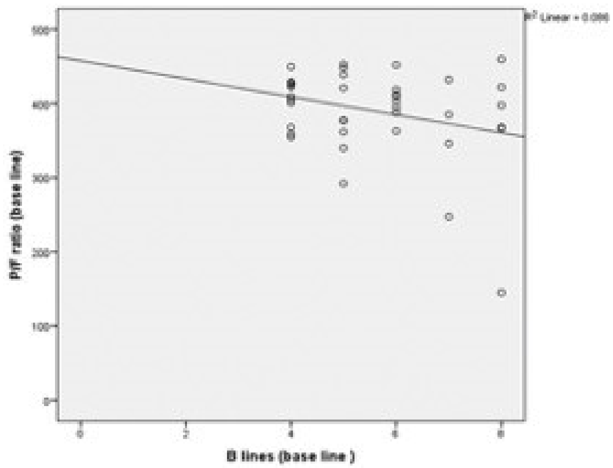

Figure 2. Scatter diagram showing correlation of B-line-score and PaO_2/FiO_2 ratio (ratio of partial pressure of arterial oxygen and the fraction of inspired oxygen) before surgery

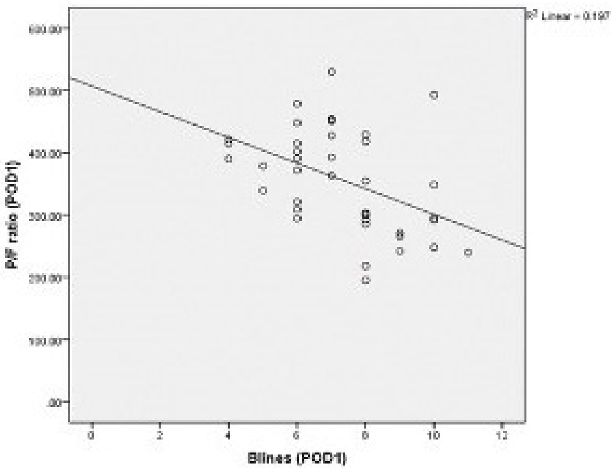

Figure 3. Scatter diagram showing the correlation of B-line score and PaO_2/FiO_2 ratio (ratio of partial pressure of arterial oxygen and a fraction of inspired oxygen) 24 h after surgery

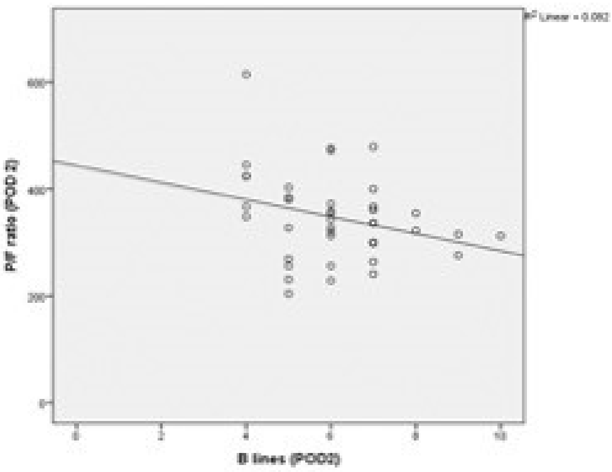

Figure 4. Scatter diagram showing the correlation of B-line score and PaO_2/FiO_2 ratio (ratio of partial pressure of arterial oxygen and a fraction of inspired oxygen) 48 h after surgery

surgeries. Fluid balance and B-line scores demonstrated a weak positive correlation 24 hours post-surgery. B-line scores revealed a moderate statistically significant negative correlation at 24 hours post-surgery with the PaO_2/FiO_2 ratio. A mean PCWP of 10.83 on the day of surgery was associated with an increased B-line score greater than 5 at 24 hours post-surgery. Fluid balance and PaO_2/FiO_2 ratios at 24 and 48 hours post-surgery showed no significant correlation.

Excess extravascular lung water leads to low oxygenation, reflected in low PaO_2/FiO_2 ratios. Low PaO2/FiO2 ratios are associated with a higher incidence of post-operative atrial fibrillation, longer ICU stays, and increased mortality (7). Elevated extravascular lung water (EVLW) following cardiac surgery predicts the outcomes of such procedures (8,9). An increase in EVLW after cardiac surgery is believed to be caused by the disruption of the endothelial glycocalyx due to hemodilution, inflammation, and ischemia-reperfusion (10). A negative fluid balance post-cardiac surgery has been shown to reduce mortality and decrease the incidence of acute kidney injury (10). It is logical to assume that a positive fluid balance correlates with increased lung water, elevated B-line scores, and a decreased PaO_2/FiO_2 ratio. However, our study's findings do not support this assumption;

Our study compares the ultrasound-based B-line score correlation with the traditionally practiced net daily fluid balance to predict hypoxemia after cardiac surgery. The ultrasound images of some of the patients with thick chest walls were suboptimal. The varying B-line phenotypes were difficult to interpret even by experienced sonographers. Additionally, we could not eliminate clinical conditions that would confound the diagnosis, like interstitial lung diseases, pulmonary fibrosis, physiological B-lines, and lung atelectasis. Ultrasound is an operator-dependent tool, so there is a risk of intra- and inter-observer variability. Incorporating artificial intelligence in scanning and identifying the B-line phenotypes will help reduce this bias and allow for faster analysis. This will require multidisciplinary work.

Conclusion

It is concluded that the B-line score depicted a significant negative correlation with the PaO_2/FiO_2 ratio at 24 hours following off-pump CABG surgery. The traditional method of fluid balance failed to show a significant correlation to the PaO_2/FiO_2 ratio at 24 or 48 hours post-surgery. Lung-ultrasound-based 4-sector protocol for B-line scoring may be used as a simple bedside tool for predicting hypoxemia due to excess EVLW. It may also help tailor fluids and diuretics in off-pump CABG surgery patients.

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Authors' Contribution

Conceptualization: Thushara Madathil.
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Software: Sunil Rajan.
Supervision: Sunil Rajan.
Validation: Sunil Rajan.
Visualization: Sunil Rajan.
Writing–original draft: Thushara Madathil.

Competing Interests

None.

Ethical Approval

The study was approved by the Ethics Committee of Amrita School of Medicine (approval number: ECASM-AIMS-2022-124, dated 07-01-2022). The study was conducted according to the principles of the Declaration of Helsinki, 2013, and good clinical practice.

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