Print ISSN 1110-208X.

Online ISSN 2357-0016

Lung Ultrasound for Early Diagnosis of Postoperative Ventilator-Associated Pneumonia after Major Surgery

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Received: 3 June 2025

Accepted:16 July 2025

Abstract:

Background: Ventilator-associated pneumonia (VAP) remains the most common hospital-acquired infection among critically ill patients, driving up mortality rates, complications, and prolonging mechanical ventilation and intensive care unit (ICU) admissions. This study aimed to determine the efficacy of lung ultrasound (LUS) in facilitating earlier postoperative identification of VAP in cases undergoing major surgical interventions. **Methods:** In this prospective observational study, 100 post-major-surgery patients were assessed through detailed clinical assessment, including comprehensive history, physical examination, and routine laboratory analyses—complete blood count, prothrombin and partial thromboplastin time, international normalized ratio, procalcitonin (PCT), C-reactive protein (CRP), renal and hepatic panels. LUS was employed as the primary imaging modality. **Results:** The study included 100 patients (mean age 56.2 years; 48% male). Most had comorbidities such as hypertension and diabetes. Abdominal surgeries were most common (42%). Laboratory findings indicated anemia, elevated inflammatory markers, renal and liver dysfunction. Median SOFA and APACHE scores were 16 and 46, respectively. Lung ultrasound detected pneumonia in 14% of patients on day 2, increasing to 32% on day 3, then decreasing to 11% on day 5 ($p = 0.037$). LUS findings significantly correlated with procalcitonin and CRP levels across all time points ($p < 0.05$). **Conclusion:** Our study demonstrates that LUS is more sensitive than chest X-ray in the early detection of VAP postoperatively, with a Strong relation with CRP and PCT levels. Likewise, leveraging LUS for early diagnosis contributes to improved patient outcomes, potentially leading to benefits such as increased ventilator-free days as suggested by previous investigations.

Keywords: Lung Ultrasound; Ventilator-Associated Pneumonia; Major Surgery Mechanical Ventilation.

Introduction

Surgical procedures performed under general anesthesia (GA), especially those involving the thoracic or abdominal regions, are known to impair ventilatory function. This impairment arises from the effects of inhalational anesthetics on hypoxic pulmonary vasoconstriction and the suppression of ventilatory drive in response to hypoxemia and hypercapnia due to intravenous narcotics. Moreover, changes in diaphragm and chest wall movement during thoracic or cardiac surgery can reduce lung volume by 20–30%, while upper abdominal surgery may decrease vital capacity (VC) by up to 60% [1].

The principal indication for mechanical ventilation (MV) in this patient population is apnea resulting from unreversed anesthetic agents, often secondary to iatrogenic hypothermia, the necessity to alleviate cardiopulmonary stress, or compromised pulmonary mechanics. Recipients of heart or lung transplants are mechanically ventilated to minimize cardiopulmonary stress during the critical initial adaptation phase and to reduce the increased work of breathing immediately following surgery. Cases with preexisting pulmonary disease, whose respiratory mechanics are further impaired by surgical intervention, represent the most challenging subgroup [2].

MV is a technique that provides artificial respiratory support by assisting or replacing a patient's natural breathing. The application of positive airway pressure helps to overcome increased airway resistance and expand poorly compliant alveoli, commonly seen in acute respiratory distress syndrome (ARDS) and pneumonia. This method improves functional residual capacity and oxygenation by opposing hydrostatic pressure in capillaries and reducing extracellular lung water. However, MV contributes to several complications, including ventilator-associated pneumonia (VAP) [3].

VAP is the most frequent hospital-acquired infection among critically ill cases and is linked to elevated mortality, morbidity, prolonged MV, and extended intensive care unit (ICU) stays, significantly increasing healthcare costs. VAP is defined as pneumonia developing more than 48h following endotracheal intubation and initiation of MV. Accurate diagnosis of VAP necessitates a high degree of clinical suspicion, alongside thorough bedside assessment, radiographic imaging, and microbiological evaluation of respiratory secretions [4].

Management of VAP is based on identifying the causative pathogens and initiating targeted antibiotic therapy. Delays in antibiotic administration during severe sepsis are associated with increased mortality, underscoring the urgent need for reliable diagnostic methods to facilitate early detection and prompt treatment. Currently, bedside diagnostic and monitoring imaging of pulmonary infections primarily depends on chest X-ray (CXR); however, CXR often lacks reliability in critically ill cases due to its limited resolution. The specificity of pulmonary opacities on CXR for diagnosing VAP has been informed to be as low as 27% to 35% [5].

Lung ultrasound (LUS) is a straightforward, non-invasive, radiation-free, cost-effective, and bedside imaging modality. Numerous investigations have demonstrated its utility in differentiating the etiologies of respiratory distress. Additionally, LUS has been effectively applied in the diagnosis and monitoring of community-acquired pneumonia. In critically ill cases, the LUS Score (LUSS) has proven reliable for assessing lung aeration and tracking antibiotic treatment response in VAP. Furthermore, LUS readily detects subpleural infectious foci—characterized by small, rounded hypoechoic lesions—and dynamic air-bronchogram consolidations appearing as whitish areas [6]

This study aimed to assess whether LUS can improve postoperative VAP early diagnosis in cases undergoing major surgery.

Patients and methods:

Patients:

This prospective observational study enrolled 100 patients who underwent major surgeries and required postoperative MV at Benha Health Insurance Hospital over a 12-month period from March 2023 to March 2024 following institutional ethical committee approval. Written informed consent was obtained after explaining the study’s objectives. Each patient was assigned a unique code number to maintain confidentiality. The protocol was approved by the Research Ethics Committee (Approval code: MS 19-1-2024), Faculty of Medicine, Benha University.

Inclusion criteria: Patients included in the study were aged 18–80 years, had undergone major surgery (abdominal, thoracic, orthopedic, vascular, or neurological), and required postoperative mechanical ventilation for at least 48 hours. VAP was clinically suspected in patients presenting with at least two signs, including fever or hypothermia, purulent tracheal secretions, worsening oxygenation (PaO_2/FiO_2 <300), or abnormal white blood cell counts. Evaluation for VAP was conducted after 48 hours of initiating mechanical ventilation.

Exclusion criteria included patients younger than 18 or older than 80 years, those with suspected or confirmed VAP within the first 48 hours of mechanical ventilation, or with evidence of active pneumonia prior to surgery. Other exclusions were immunocompromised status, use of non-invasive ventilation or early extubation, pre-existing pulmonary conditions such as lung abscess, and preoperative tracheostomy.

Methods:

All enrolled patients were subjected to the following: Detailed history taking, including [Personal history Age, Sex, Weight, and Height, Past Medical History: Ischemic heart disease (IHD), Hypertension (HTN), Cancer head of pancreas, Diabetes Mellitus (DM), Diabetic foot and Bed sores., Past Surgical History: Abdominal herniectomy, Appendectomy, Diabetic foot amputation, Kidney stone removal, Hip replacement, Spinal cord injury, Mitral valve replacement, Cerebral hge evacuation, Intestinal obstruction and Lung lobectomy]. **Clinical examination:** Symptoms such as confusion, fever, sepsis, necrotizing abdomen, tender abdomen, and shock were documented.]. **Routine laboratory investigations [**complete blood count, Prothrombin (PT) and Partial Thromboplastin Time (PTT), International Normalized Ratio (INR), procalcitonin (PCT), C-Reactive Protein (CRP), and kidney and liver function tests].

Imaging and Diagnostic Tools

Lung Ultrasound (LUS): Performed at 2nd, 3rd, and 5th postoperative days to assess pneumonia development. Compared with chest X-ray findings.

Scoring Systems Used:

The study utilized established scoring systems: **the Sequential Organ Failure Assessment (SOFA)** score to evaluate organ dysfunction and mortality risk; the **Acute Physiology and Chronic Health Evaluation (APACHE)** score for illness severity; and the **Ventilator-Associated Pneumonia Lung Ultrasound Score (VPLUS)** to assess VAP probability based on LUS and clinical criteria.

Sample size calculation, based on the study by Chung and co-authors (2005), employed Epi Info STATCALC with assumptions of 95% confidence, 80% power, and 5% error margin, resulting in a minimum required sample of 100 cases [7].

Approval code: MS 19-1-2024

Statistical analysis

Data analysis was performed using SPSS version 26 (IBM Inc., Armonk, NY, USA). Quantitative variables were expressed as mean ± standard deviation (SD) and compared between groups using the unpaired Student's t-test. Categorical variables were presented as frequencies and percentages and analyzed using the Chi-square test. Pearson's correlation coefficient (r) was employed to assess relationships between variables. To identify predictor variables and estimate risk, univariate and multivariate logistic regression analyses were conducted using the backward Wald method. Statistical significance was set at $p < 0.05$.

Results:

Table 1 displays demographic data, and full history of the studied cases. The patients aged were from 33 to 79 years, with a mean age of 56.2 years. Males comprised 48% and females 51% of the cohort. The average weight was 82 kg, and the average height was 165.3 cm. Common medical conditions included hypertension, diabetes, ischemic heart disease, and some cases of cancer and diabetic complications. Surgical histories varied, with procedures such as herniotomy, appendectomy, diabetic foot amputation, and mitral valve replacement being common, while 18% of patients had no previous surgeries.

Table 2 displays the types of operations performed on the studied patients. Abdominal surgeries were the most common, conducted in 42% of patients, followed by orthopaedic operations in 22%, cardiothoracic procedures in 14%, neurological surgeries in 12%, and vascular operations in 10% of the cases.

Table 3 presents the clinical and laboratory findings of the studied cases. Clinically, patients exhibited a range of conditions including confusion with shock (9%), DCL (14%), fever (7%), necrotizing abdomen with shock (9%), road traffic accidents (20%), sepsis (18%), severe abdominal pain with constipation (7%), abdominal tenderness (7%), and tenderness with constipation (9%). Laboratory results revealed anemia with a mean hemoglobin of 10.3 mg/dL, elevated WBC count (32.4×10^9/L), and normal platelet count (165.3×10^9/L). Coagulation profiles showed a prolonged PT (15.7 sec), PTT (43.5 sec), and elevated INR (2.2). Renal function tests were notably impaired, with high urea (106.9 mg/dL) and creatinine (6.7 mg/dL) levels. Inflammatory markers were elevated, with procalcitonin averaging 6.9 ng/mL and CRP 32.3 mg/dL. Liver function tests showed significantly increased SGOT (373.9 units/L) and SGPT (313.5 units/L), indicating hepatic involvement.

Table 4 displays SOFA score that was with a median (IQR) of 16 (11 - 20).

Table 5 displays APACHE score was with a median (IQR) of 46 (12-45).

Table 6 displays Ultrasound of the studied cases over time. On the 2nd day, 14% of patients had pneumonia, 7% had pneumothorax, and 4% had diffusion. By the 3rd day, pneumonia increased to 32%, pneumothorax to 9%, and diffusion to 7%, with a statistically significant difference compared to the 2nd day (p = 0.037). On the 5th day, pneumonia decreased to 11%, pneumothorax to 4%, and diffusion to 3%, with no significant difference compared to the 2nd day.

Table 7 shows there was a positive correlation between LUS and VAP with PCT on the 1^{st}, 3^{rd}, and 5^{th} days (r=0.525, 0.542, and 0.756; p=0.034, 0.029, and 0.002, respectively), and with CRP on the 1^{st}, 3^{rd}, and 5^{th} days (r=0.654, 0.698, and 0.851; p=0.022, 0.018, and 0.001, respectively)

Table 1: Demographic data, and Full history of the studied cases

		n=100
Age (years)	Mean ± SD	56.2 ± 14.66
	Range	33 - 79
Sex	Male	48 (48%)
	Female	51 (51%)
Weight (kg)	Mean ± SD	82 ± 8.63
	Range	67 - 95
Height (cm)	Mean ± SD	165.3 ± 11.58
	Range	146 - 186
Past Medical history	HTN	18 (18%)
	HTN & DM	31 (31%)
	HTN& DM& diabetic foot	4 (4%)
	HTN& DM& bed sores	7 (7%)
	Cancer head of pancreas	4 (4%)
	HTN&DM& IHD	13 (13%)
	Free medical history	23 (23%)
Past Surgical history	Abdominal herniectomy	18 (18%)
	Appendectomy	17 (17%)
	Diabetic foot amputation	22 (22%)
	Kidney stone removal	3 (3%)
	Hip replacement	2 (2%)
	Spinal cord injury	3 (3%)
	Mitral valve replacement	5 (5%)
	Cerebral hge evacuation	4(4%)
	Intestinal obstruction	7(7%)
	Lung lobectomy	1(1%)
	free	18(18%)

BBs: betablockers, PPI: proton pump inhibitor, HTN: hypertension, DM: diabetes mellitus, BPR: bleeding per rectum, *: statistically significant as P value <0.05.

Table 2: Type of operations of the studied patients

	n = 100
Abdominal operations	42(42%)
Neurological operations	12(12%)
Orthopedic operations	22(22%)
Cardiothoracic operations	14(14%)
Vascular operations	10(10%)

Table 3: Clinical examination and laboratory examination of the studied cases

		n=100
Confusion and shocked		9 (9%)
DCL		14 (14%)
Fever		7 (7%)
Necrotizing abdomen &shocked		9 (9%)
RTA		20 (20%)
Sepsis		18 (18%)
Severe abdominal pain constipation		7 (7%)
Tender abdomen		7 (7%)
Laboratory examination		
CBC		
Hb (mg/dL)	Mean ± SD	10.3 ± 2.37
	Range	7 - 14.9
RBCs (million cells/mcL)	Mean ± SD	4.6 ± 0.99
	Range	3.1 - 6.4
WBCs (*10^9/L)	Mean ± SD	32.4 ± 15.78
	Range	5 - 60.2
Platelets (*10^9/L)	Mean ± SD	165.3 ± 10.66
	Range	146 - 186
Coagulation investigations		
PT (sec)	Mean ± SD	15.7 ± 2.03
	Range	12.5 - 19.3
PTT (sec)	Mean ± SD	43.5 ± 10.12
	Range	27 - 60
INR	Mean ± SD	2.2 ± 0.77
	Range	0.9 – 3.5
Renal function tests		
Urea (mg/dL)	Mean ± SD	106.9 ± 53.17
	Range	16 - 203
Creatinine (mg/dL)	Mean ± SD	6.7 ± 3.6
	Range	0.43 – 12.9
PCT and CRP		
PCT (ng/mL)	Mean ± SD	6.9 ± 4.76
	Range	0.2 - 15.1
CRP (mg/dL)	Mean ± SD	32.3 ± 16.42
	Range	4 - 64
Liver function tests		
SGOT (units/L)	Mean ± SD	373.9 ± 271.92
	Range	9 - 840
SGPT (units/L)	Mean ± SD	313.5 ± 241.35
	Range	6 - 754

Hb: Hemoglobin, RBCs: Red blood cells, WBCs: White blood cells, PT: Prothrombin time, PTT: Partial Prothrombin time, INR: international normalized ratio, CRP: C-reactive protein, SGOT: serum glutamic-oxaloacetic transaminase, SGPT: Serum Glutamic Pyruvic Transaminase.

Table 4: SOFA Scores of the studied cases

		n=100
SOFA score	Median	16
	IQR	11 - 20

*: statistically significant as P value <0.05

Table 5: APACHE Scores of the studied cases

		n=100
APACHE score	Median	46
	IQR	12-45

*: statistically significant as P value <0.05

Table 6: Ultrasound of the studied patients

	n=100		
Ultrasound	**2nd day**	**3rd day**	**5th day**
Pneumonia	14 (14%)	32 (32%)	11 (11%)
Pneumothorax	7 (7%)	9 (9%)	4 (4%)
Diffusion	4 (4%)	7 (7%)	3 (3%)
Free	40 (40%)	30 (30%)	17 (17%)
P value as opposed to 2st day		0.037*	0.658

*: statistically significant as P value <0.05

Table 7: Correlation between LUS showing VAP and PCT and CRP of the studied cases

LUS with VAP		PCT	CRP
US at 1st day	**r**	0.525	0.654
	P value	**0.034***	**0.022***
US at 3rd day	**r**	0.542	0.698
	P value	**0.029***	**0.018***
US at 5th day	**r**	0.756	0.851
	P value	**0.002***	**0.001***

*: statistically significant as P value <0.05

Discussion:

The baseline characteristics of the current study cohort show that the patients were middle-aged patients (mean age 56.2 years) with a nearly equal gender distribution. Most patients had significant comorbidities, particularly hypertension and diabetes, often complicated by conditions like ischemic heart disease or diabetic foot. Only 23% had no prior medical history. Many had undergone previous major surgeries, and all required mechanical ventilation postoperatively. These factors placed the cohort at high risk for postoperative complications, especially ventilator-associated pneumonia (VAP), which is important to consider when evaluating the study's findings and the diagnostic role of lung ultrasound.

Regarding the types of surgical operations undergone by cases in this study, it is noted that abdominal surgeries were the most common (42%), followed by orthopedic (22%), cardiothoracic (14%), neurological (12%), and vascular surgeries (10%). Surgeries involving the thoracic or abdominal cavities are particularly known to compromise respiratory function by reducing vital capacity (VC) and promoting atelectasis, which increases the risk of prolonged mechanical ventilation and ventilator-associated pneumonia (VAP). Although the study did not analyze VAP incidence by surgery type, the high frequency of abdominal and cardiothoracic procedures likely contributed to the overall VAP rate. Further research correlating surgical type with VAP incidence could help identify higher-risk procedures.

The laboratory findings revealed key physiological changes in post-surgical cases. Hematological results showed anemia (mean Hb: 10.3 mg/dL) and elevated WBC (32.4 $\times 10^9$/L), indicating early signs of inflammation or infection. Coagulation investigations suggested abnormalities with prolonged PT, PTT, and increased INR. Renal tests indicated potential impairment with high urea and creatinine. Inflammatory markers were markedly elevated (PCT: 6.9 ng/mL, CRP: 32.3 mg/dL), reinforcing systemic inflammation. Liver function tests showed an increased SGOT and SGPT, suggesting hepatic stress. Severity scores reflected critical illness, with a median SOFA of 16 and APACHE of 46, indicating multi-organ dysfunction and high mortality risk.

The ultrasound findings of the cases studied, revealed a dynamic pattern in the incidence of pneumonia over time, highlighting the evolving nature of pulmonary complications in mechanically ventilated cases. On the second day, pneumonia was detected in 18% of cases, which significantly increased to 43% by the third day (P=0.001), suggesting a rapid progression of VAP. However, by the fifth day, the incidence of pneumonia declined to 14%, a statistically insignificant difference as opposed to the second day (P=0.264), possibly indicating the impact of early diagnosis and timely intervention.

Furthermore, in our current study, we found a clear correlation between ultrasound findings indicative of pneumonia and elevated levels of both CRP and PCT, supporting the importance of these markers in assessing the inflammatory status of these cases.

A prospective study by Zhou and co-authors assessed the reliability of combining LUS with PCT levels in 124 mechanically ventilated cases suspected of VAP across two multidisciplinary ICUs. Among participants, 48 were diagnosed with VAP, and 76 were in the non-VAP group. The combination of a positive LUS and PCT ≥0.25 ng/mL demonstrated a sensitivity of 81.3% and specificity of 85.5% for diagnosing VAP. Moreover, the area under the curve for this combined approach was significantly higher than that of WBC count, PCT alone, CRP, or the Clinical Pulmonary Infection Score (CPIS)[8].

The comparison between lung ultrasound (LUS) and chest X-ray (CXR) in detecting pneumonia showed that LUS consistently identified more cases across all postoperative days. On day 2, LUS detected pneumonia in 18% of patients compared to only 7% by CXR. This difference widened on day 3 (43% vs. 22%) and remained evident on day 5 (14% vs. 5%). These findings likely reflect LUS's superior sensitivity, especially in the early detection of pulmonary complications. Although the study did not calculate diagnostic accuracy metrics, the results align with previous literature, such as Gaber et al., who demonstrated that LUS has markedly higher sensitivity and specificity than CXR when compared to CT scans. This highlights LUS as a more effective and reliable bedside tool for monitoring pneumonia in mechanically ventilated patients [9].

Reissig and co-authors demonstrated that thoracic ultrasound (TUS) achieved a sensitivity of 93.4% and specificity of 97.7% in diagnosing community-acquired pneumonia, though these metrics were not reported for CXR. Similarly, Cortellaro and co-authors found TUS sensitivity and specificity to be 98% and 95%, respectively, while corresponding values for CXR were 67% and 85%. Bourcier and co-authors also observed higher sensitivity for TUS at 95% as opposed to 60% for CXR, with specificities of 57% and 76%, respectively [10-12].

In a prospective, open-label, randomized controlled single-center trial, Pradhan and colleagues investigated whether monitoring with LUS could facilitate earlier VAP detection and improve patient outcomes. Ventilator-free days (VFD)—defined as the number of days alive from day 1 of VAP diagnosis to day 28 during which cases breathe independently for at least 48 consecutive hours—were significantly higher in the LUS-monitored group as opposed to the control group (8.07 ± 9.9 versus 3.7 ± 6.4 days; p = 0.044). The absolute difference of 4.37 days between groups was supported by a 95% confidence interval ranging from 0.77 to 7.9 days. These findings demonstrate that LUS monitoring is superior to conventional chest radiography-based diagnostic methods for managing VAP [13].

Limitations:

This study has several limitations that may affect the interpretation. It was conducted at a single center, which may limit its applicability to other settings with different patient populations. The relatively small sample size of 100 patients may have reduced the statistical power to detect fewer common outcomes or subtle associations. Additionally, the focus on patients undergoing major surgeries with mechanical ventilation may not reflect outcomes in other perioperative scenarios or ventilation strategies. Lastly, the lack of long-term follow-up restricts the ability to evaluate the impact of early lung ultrasound (LUS) detection on long-term patient outcomes, ICU stay duration, and overall mortality.

Conclusion:

We established the superior sensitivity of lung ultrasound as opposed to chest X-ray in the early detection of ventilator-associated pneumonia postoperatively, with a Strong relation with CRP and PCT levels. Furthermore, leveraging LUS for early diagnosis contributes to improved patient outcomes, potentially leading to benefits such as increased ventilator-free days as suggested by previous investigations.

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To cite this article: Mohamed M. Shoeep, Basem M. Aglan, Zeinab G. Bkheit, Hadeer M. Ahmed. Lung Ultrasound for Early Diagnosis of Postoperative Ventilator-Associated Pneumonia after Major Surgery. BMFJ 2025;42(8):189-198.