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A 62-Year-Old Man With Rapidly Progressive Hypoxemia

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A 62-year-old man with type 2 diabetes presented to the ED with 2 weeks of worsening dyspnea and generalized malaise. He was admitted because of viral pneumonia from severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection, and he needed oxygen supplementation with 2 L via nasal cannula. On day 5 of hospitalization, a rapid response was called for acute hypoxemic respiratory failure, and the patient was transferred to the medical ICU on high-flow nasal cannula and non-rebreather mask. On arrival, he quickly decompensated further, progressing to septic shock, and was urgently placed on invasive mechanical ventilation. His initial vital signs in the ICU were temperature 38.9°C, heart rate 153 beats/min, respirations 42 breaths/min, BP of 97/67 mm Hg on a norepinephrine infusion, and arterial oxygen saturation 91% on 100% FIO2. After intubation, his ratio of PaO2/FIO2 was 75 on 12 cm H2O of positive end-expiratory pressure. To evaluate the cause of his rapidly progressive hypoxemia, a point-of-care lung ultrasound was performed (Videos 1, 2).

Question 1: Based on the findings on lung ultrasound (Video 1), what is the likely diagnosis?

Question 2: What is the pathophysiologic significance of the lung ultrasound finding shown (Video 2), and how could its presence affect management?
**Answer 1:** ARDS from viral pneumonia with superimposed bacterial pneumonia. Video 1 demonstrates diffuse bilateral anterior B-lines with small areas of subpleural consolidation. The B-lines are likely from noncardiogenic pulmonary edema, likely from viral pneumonia. There is also a dense lobar consolidation at the right base with dynamic air-bronchograms, suggesting the presence of superimposed bacterial pneumonia.

**Answer 2:** Video 2 demonstrates color Doppler ultrasound identifying the presence of pulmonary vessels pulsating with the cardiac cycle within consolidated lung. This finding represents the sonographic identification of intrapulmonary shunt and ventilation-perfusion (V/Q) mismatch: the presence of perfusion to collapsed alveolar units, which are unable to participate in gas exchange. Given the patient’s profound hypoxemia, the identification of suspected bacterial pneumonia with intrapulmonary shunt triggered a number of management decisions: (1) the patient underwent diagnostic and therapeutic bronchoscopy for secretion clearance to restore airway patency of the right lung. Bronchoscopy showed copious purulent secretions along the basilar branches of the right lower lobe, which cultured methicillin-sensitive *Staphylococcus aureus* (MSSA) and *Escherichia coli*. Notably, the patient later developed bacteremia from these same organisms; (2) to redirect perfusion to healthy lung units, the patient received inhaled epoprostenol to reduce shunt fraction and improve V/Q mismatch; (3) we decided against administering tocilizumab, an anti-interleukin-6 receptor monoclonal antibody, because of the suspected concurrent bacterial infection; (4) the patient underwent prone positioning for severe ARDS and to reorient blood flow. The combination of these measures led to significant improvement in hypoxemia over the following days, and the patient no longer required prone positioning by ICU day 5. Although his hypoxemia improved, the patient experienced a prolonged ICU course, eventually undergoing tracheostomy and transfer to the general medical floors on ICU day 22.

**Discussion**

Our case demonstrates the importance of comprehensive lung ultrasound in patients with hypoxemic respiratory failure. During the current SARS-CoV-2 pandemic, critical care physicians have become inundated with cases of viral pneumonia in which radiography often depicts the presence of diffuse pulmonary opacities across multiple lung fields. Consequently, the utility of employing lung ultrasound to further investigate the cause of respiratory failure may be more frequently omitted. However, as our case demonstrates, multifactorial causes of hypoxemia can be present, especially in patients infected with SARS-CoV-2 who have increased risk of superimposed bacterial pneumonia, pneumothorax, or pneumomediastinum, venous thromboembolic disease, cardiogenic pulmonary edema, and more.

Point-of-care lung ultrasound identified an asymmetric lobar consolidation in the right base of the patient, with the presence of dynamic air-bronchograms. Air-bronchograms are linear punctiform hyperechogenicities representing air within bronchi and may be dynamic or static in nature, depending on the mobility of the gas with respiration. Dynamic air-bronchograms have been shown to yield a sensitivity and specificity of 61% and 94% for bacterial pneumonia—the mechanism by which pneumonias develop may explain why this association exists. The development of bacterial pneumonia requires that a pathogen reach the alveoli, overwhelm local immune defenses, and cause alveolar exudate formation, leading to progressive alveolar collapse and eventually lung consolidation. Because alveolar consolidations propagate from a distal-to-proximal arrangement, air can still flow through patent subsegmental bronchi throughout this process, which are visualized as dynamic air-bronchograms on ultrasound. In contrast with this, obstructive atelectasis from a proximal airway obstruction (ie, acute mucus plug) can be accompanied by the presence of static air-bronchograms: immobile hyperechogenicities reflecting trapped residual bronchial gas distal to the site of obstruction. As described, identification of dynamic air-bronchograms triggered a number of significant clinical
decisions for the patient, targeted toward managing a superimposed bacterial infection.

As seen in Video 2, color Doppler identified pulsating pulmonary vessels within the consolidation, signifying intrapulmonary shunt with V/Q mismatch. Pulmonary vascular morphology and hemodynamic changes in pulmonary consolidations have rarely been reported in the literature. Mongodi et al described a patient with hypoxic respiratory failure with postobstructive atelectasis in a case of diffuse alveolar hemorrhage. The authors identified significant intrapulmonary shunt by color Doppler within lobar consolidations. After bronchoscopic clearance of blood clots, the authors reported a dramatic improvement in oxygenation after reaeration of the obstructed pulmonary lobes. In a study of 31 adults admitted with suspected pneumonia, Kader and Osman identified intrapulmonary shunt by color Doppler within consolidations in over 65% of the study sample.

Hypoxemia in early pneumonia is principally caused by a relative failure of the hypoxic pulmonary vasoconstriction mechanism leading to persistent blood flow to consolidated lung, causing intrapulmonary shunt and V/Q mismatch. Although endogenous vasodilators associated with the inflammatory process are likely involved, sepsis-mediated vasodilation and hyperemia from increased metabolic demand and microcirculatory dysfunction also may play a prominent role. Indeed, regional sepsis may exacerbate intrapulmonary shunting, worsening hypoxemia while also dysregulating the vascular endothelium. We noted the patient to have polymicrobial bacteremia from the same organisms cultured from the patient’s bronchial samples, suggesting that increased blood flow to infected alveolar units may have allowed invasive pathogens access to the systemic circulation, ultimately leading to bacteremia. Although pathophysiologically reasonable, whether pulmonary vessels identified by color Doppler within consolidations is a sonographic feature of bacterial pneumonia, and whether infection increases the likelihood of this finding, remain unclear. As described, the patient’s hypoxemia improved over time, and by ICU day 5, color Doppler over the right basilar consolidation showed a paucity of identifiable pulmonary vessels (Video 3). This improvement in V/Q mismatch is likely a consequence of recovery of hypoxic pulmonary vasoconstriction with successful treatment of bacterial pneumonia, and through redirection of blood flow through inhaled epoprostenol. See Narration Video for a detailed explanation of Videos 1-3.

A comprehensive lung ultrasound should be performed in all patients with acute hypoxemic respiratory failure. Although other diagnostic modalities can provide meaningful clinical information, lung ultrasound has been shown to outperform chest radiography in numerous common conditions causing acute respiratory failure in critically ill patients, including pneumonia. As our case demonstrates, multifactorial causes of hypoxemia may coexist, and identifying such conditions can dramatically affect clinical decision-making and patient management.

Reverberations

1. Multiple causes of acute hypoxemic respiratory failure may coexist, and a comprehensive lung ultrasound should be performed in all cases during evaluation of the critically ill patient.

2. Dynamic air-bronchograms can be identified as punctiform hyperechogenicities within consolidations that move with the respiratory cycle, and are highly suggestive of bacterial pneumonia.

3. In patients with hypoxemia, color Doppler can identify pulmonary vessels within consolidations, and their presence signifies intrapulmonary shunt with V/Q mismatch: the presence of perfusion to collapsed alveolar units that do not participate in gas exchange.

4. Management of intrapulmonary shunt and V/Q mismatch can include (1) restoration of ventilation by reaeration of consolidated lung by therapeutic bronchoscopy or positive end-expiratory pressure titration and (2) improving perfusion matching by reorienting blood flow through patient positioning or inhaled pulmonary vasodilators.

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Additional information: Videos for this case are available under “Supplementary Data.”

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