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PARADOXICAL HYPOXEMIA FOLLOWING POSITIVE PRESSURE VENTILATION: EXPLORING THE PATHOPHYSIOLOGY

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ABSTRACT

Positive pressure ventilation (PPV), both non-invasive and invasive, enhances ventilation but can sometimes lead to unexpected hypoxemia. This case report describes an instance of paradoxical hypoxemia after initiating bilevel positive airway pressure (BiPAP) in a 58-year-old female with a medical history of systemic lupus erythematosus, interstitial lung disease, and pulmonary embolism. BiPAP was started, leading to improved hypercarbia but worsened hypoxemia. Further investigation revealed a right-to-left interatrial shunt via a small patent foramen ovale (PFO). Adjusting BiPAP settings improved arterial blood gas parameters. This case illustrates how positive pressure ventilation with underlying PFO can cause paradoxical hypoxemia. The case emphasizes the importance of understanding the pathophysiology and tailoring BiPAP settings based on individual haemodynamics.

KEYWORDS

Hypoxemia, positive pressure ventilation, patent foramen ovale, shunt

LEARNING POINTS

- Positive pressure ventilation can trigger paradoxical hypoxemia through a right-to-left shunt in patients with patent foramen ovale.
- Unexplained hypoxemia after initiating positive pressure ventilation warrants investigating intracardiac shunts with a saline contrast echocardiogram.
- Adjusting bilevel positive airway pressure settings based on individual haemodynamics is essential for improving oxygenation.

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INTRODUCTION

We present a case of paradoxical hypoxemia following positive pressure ventilation (PPV) in a patient with acute on chronic pulmonary conditions, revealing a previously undiagnosed small patent foramen ovale (PFO). This report explores the pathophysiology of this phenomenon and emphasizes the importance of thorough diagnostic evaluations and personalized ventilatory strategies.

CASE DESCRIPTION

A 58-year-old woman presented with worsening dyspnoea and cough over several weeks, along with occasional episodes of aspiration. Her medical history included systemic lupus erythematosus (SLE), interstitial lung disease (ILD), and pulmonary embolism (PE) diagnosed a year prior, for which she had been treated with apixaban. Despite being hemodynamically stable and maintaining 100% oxygen saturation with supplemental oxygen (2 l/min via nasal cannula), arterial blood gas (ABG) indicated significant hypercapnia and respiratory acidosis *(Table 1)*. A chest computed tomography (CT) scan revealed patchy multifocal infiltrates, especially in the left lung base and increased dilation of the pulmonary arteries compared to previous scans (*Fig. 1A and 1B)*. Additionally, there was evidence of progressive fibrosis in the lower lobes with slight worsening of traction bronchiectasis, reticular opacities, and honeycombing, concerning for worsening ILD.

Bilevel positive pressure ventilation (BiPAP) was initiated for hypercarbia with an inspiratory positive airway pressure (IPAP) of 10 cmH_2O and an expiratory positive airway pressure (EPAP) of 5 cmH_2O with an inspiratory fraction of oxygen (FiO_2) of 30%. An hour later, ABG showed improved hypercarbia but worsened hypoxemia *(Table 1)*. Suspecting a shunt, a saline contrast transthoracic echocardiogram was performed, revealing a small right-to-left interatrial shunt *(Fig. 1C)*. Lowering BiPAP settings to an IPAP of 8 cmH_2O and an EPAP of 4 cmH_2O with an FiO_2 of 24% improved the hypoxia *(Table 1)*. Sputum culture later identified *Pseudomonas aeruginosa*, likely the cause of pneumonia. After antibiotic treatment and BiPAP adjustments, her condition improved, and she was discharged.

DISCUSSION

Positive pressure ventilation, whether non-invasive or invasive, can improve ventilation but may unexpectedly cause hypoxemia in certain scenarios, particularly in patients with an atrial septal defect or a PFO[1-3]. The foramen ovale is a natural opening between the atria that typically closes after birth but remains open in 20 to 34% of the general population[3]. When a PFO is present, deoxygenated blood from the right atrium (RA) may flow into the left atrium (LA) if the right atrial pressure (RAP) exceeds the left atrial pressure (LAP), leading to shunt and subsequent hypoxemia. A study of 46 mechanically ventilated patients with respiratory failure, all on positive end-expiratory pressure (PEEP) ≥5 cmH_2O and FiO_2 ≥50%, found that 15% of them had a PFO[1]. In those with PFO, increasing PEEP raised the right-to-left shunt fraction, increased the alveolar-to-arterial oxygen gradient, and decreased arterial oxygen pressure (PaO_2)[1]. PPV increases intraparenchymal pressure and may increase pulmonary vascular resistance and right ventricular (RV) afterload. This can cause elevated RA pressure. If this rise is significant enough, the increased RA:LA pressure ratio can favour right to left intracardiac shunt[2]. This effect is most common in individuals with underlying pulmonary pathologies associated with increased pulmonary

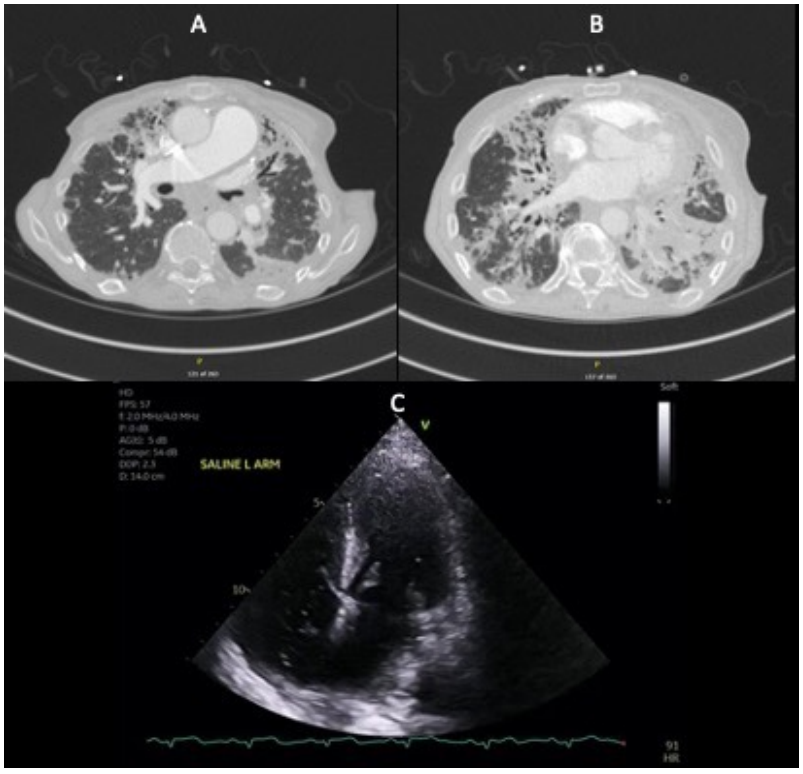


Figure 1. Computed tomography scan of the chest showing: A) The main pulmonary artery dilated to 3.6 cm, the right pulmonary artery to 2.5 cm, and the left pulmonary artery to 3.5 cm (previously 3.4, 2.1, and 3.3 cm, respectively). These findings likely indicate pulmonary arterial hypertension; B) The central airways exhibit diffuse patchy peribronchial peripheral opacity and cystic changes, along with peripheral peribronchial and subpleural cystic changes, more pronounced in the lower lobes, particularly the left lower lobe. These findings are consistent with fibrotic interstitial lung disease, with slight interval progression, most notable in the left lower lobe. Underlying infectious or inflammatory aetiologies in the area of progression cannot be excluded; (C) Saline contrast transthoracic echocardiogram highlighting the agitated saline study which appears positive for a right-to-left shunt, suggesting a small patent foramen ovale.

Arterial blood gas	Readings on 2 l/min of oxygen	Readings after 1 hour of BiPAP	Readings on BiPAP with adjusted setting	Reference range
pH	7.30	7.44	7.46	7.35-7.45
pCO_2 (mmHg)	>100	73	62	36-46
PaO_2 (mmHg)	149	44	63	85-95
Bicarbonate (mmol/l)	48	48	43	22-26
Arterial oxygen saturation (%)	99	81	93	95-98
FiO_2 (%)	27	30	24	21 (Room air)

Abbreviations: BiPAP, bilevel positive airway pressure; pH, potential of hydrogen; pCO_2, partial pressure of carbon dioxide; PaO_2, arterial partial pressure of oxygen; FiO_2, inspiratory fraction of oxygen.

Table 1. Arterial blood gas analysis.

vascular resistance such as ILD, pulmonary embolism, severe emphysema, or pulmonary arterial hypertension (PAH)[2,3]. In our patient, underlying ILD and history of PE likely predisposed her to an increased RAP. The addition of PPV in her case likely exacerbated this with subsequent interatrial shunt and hypoxemia.

PPV also raises pleural pressures which can compress the inferior vena cava and impede venous return to the RA. As a result, patients receiving PPV are at risk for decreased cardiac output and subsequent peripheral oxygen delivery (DO_2)[4]. However, this is unlikely to occur at levels of PEEP <10 cmH_2O, making it less likely the cause of hypoxemia in our patient[1,5]. Additionally, PPV can also inhibit hypoxic pulmonary vasoconstriction, leading to intrapulmonary shunting and worsening systemic oxygenation[1]. This phenomenon can occur in patients with regional lung diseases, since PPV can cause overdistension of relatively normal alveoli and subsequent increased PVR in those regions. The result causes a redistribution of blood flow toward diseased, nonaerated lung units, thus worsening ventilation-perfusion ratio and gas exchange[4]. Consequently, PPV could impair systemic oxygenation in those with regional lung diseases. Our patient's ILD progression and Pseudomonal pneumonia could have contributed to the observed hypoxemia when BiPAP was initiated, but the presence of interatrial shunting on echocardiographic bubble study suggests that he PFO was likely the dominant physiologic culprit.

CONCLUSION

Our case highlights the complex interplay between PPV and underlying cardiac or pulmonary conditions, such as PFO, PAH, ILD, and pneumonia. It underscores the importance of individualized BiPAP settings to optimize patient outcomes, and the need to reassess both ventilation and oxygenation after initiating therapy. Clinicians should be aware of the potential for paradoxical hypoxemia in patients with similar profiles and should consider thorough evaluation and appropriate adjustments to ventilatory strategies.

REFERENCES

1. Cujec B, Polasek P, Mayers I, Johnson D. Positive end-expiratory pressure increases the right-to-left shunt in mechanically ventilated patients with patent foramen ovale. *Ann Intern Med* 1993;**119**:887-894.
2. Layoun ME, Aboulhosn JA, Tobis JM. Potential Role of Patent Foramen Ovale in Exacerbating Hypoxemia in Chronic Pulmonary Disease. *Tex Heart Inst J* 2017;**44**:189-197.
3. de Picciotto C, Duménil C, Auzel O, Giraud V, Bonay M. Paradoxical worsening of hypoxemia in a patient treated by noninvasive positive pressure ventilation for obesity hypoventilation syndrome with concomitant obstructive sleep apnea: a case report. *J Med Case Rep* 2017;**11**:234.
4. Çoruh B, Luks AM. Positive end-expiratory pressure. When more may not be better. *Ann Am Thorac Soc* 2014;**11**:1327-1331.
5. Luecke T, Pelosi P. Clinical review: Positive end-expiratory pressure and cardiac output. *Crit Care* 2005;**9**:607-621.