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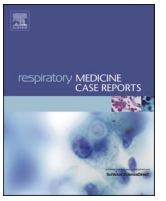

Case Report

High-frequency jet ventilation in managing airway during whole-lung lavage under general anesthesia: A case report☆

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ABSTRACT

Pulmonary alveolar proteinosis (PAP) is a rare disorder characterized by the accumulation of surfactant-derived lipoproteins within alveoli and impaired macrophage function, leading to progressive dyspnea, hypoxemic respiratory failure, secondary infections, and pulmonary fibrosis. We report a case of a 43-year-old male with a history of occupational exposure to airborne dust from lathe work, presenting with exertional dyspnea. High-resolution computed tomography (HRCT) revealed bilateral patchy ground-glass opacities with interlobular septal thickening. Histopathological analysis of lung biopsy specimens showed eosinophilic amorphous material in alveolar spaces, which exhibited positive periodic acid-Schiff (PAS) staining with diastase resistance, confirming PAP. The patient underwent whole-lung lavage (WLL) of the right lung under general anesthesia. Severe baseline hypoxemia complicated intraoperative oxygen saturation maintenance. The intermittent use of high-frequency jet ventilation (HFJV) in the operative lung markedly improved oxygenation (SpO_2 increased from 85 % to 96 %) while ensuring effective saline distribution into distal alveoli. The procedure was completed without complications, highlighting the efficacy and safety of HFJV in managing complex airway conditions during WLL for PAP.

1. Introduction

Pulmonary alveolar proteinosis (PAP) is a rare disorder characterized by dysfunctional alveolar macrophage-mediated clearance of surfactant proteins, leading to their accumulation and subsequent respiratory impairment. This pathophysiology results in progressive respiratory insufficiency, increasing the risk of hypoxemic respiratory failure and secondary infections [1]. Whole-lung lavage (WLL)—performed under general anesthesia with lung isolation, sequential saline instillation, and mechanical extraction of lipoproteinaceous debris—remains the gold-standard treatment for symptomatic PAP [2]. However, patients with severe baseline hypoxemia often develop refractory oxygen desaturation during bronchoscopic procedures, presenting significant perioperative airway management challenges.

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2. Case report

A 43-year-old male machinist with chronic occupational exposure to metalworking dust presented with a six-month history of progressive exertional dyspnea of unclear etiology. High-resolution computed tomography (HRCT) revealed bilateral, multifocal ground-glass opacities with predominant involvement of the left upper lobe and all right lung segments, accompanied by interlobular septal thickening and subpleural reticulation (Fig. 1). Transbronchial biopsy histopathology demonstrated eosinophilic, acellular material expanding alveolar spaces, showing strong periodic acid-Schiff (PAS) positivity with diastase resistance (Fig. 2). These characteristic histopathological features, combined with clinical and radiological findings, established the diagnosis of pulmonary alveolar proteinosis (PAP). Following multidisciplinary evaluation, therapeutic right-sided whole-lung lavage (WLL) under general anesthesia was recommended.

Preoperative pulmonary function tests revealed moderate restrictive ventilatory impairment with decreased diffusing capacity for carbon monoxide (DLCO), while the residual volume to total lung capacity (RV/TLC) ratio remained normal. Room air arterial blood gas analysis prior to induction showed compensated respiratory acidosis (pH 7.401) with severe hypoxemia (PaO_2 50.4 mmHg, $PaCO_2$ 34.7 mmHg) and mildly elevated lactate (1.9 mmol/L; base excess −2.8, SpO_2 90.1 %). Standard intraoperative monitoring was established, incorporating five-lead electrocardiography, invasive radial artery pressure measurement, pulse oximetry, and transcutaneous carbon dioxide monitoring. Premedication consisted of intravenous methylprednisolone 40 mg (for anti-inflammatory prophylaxis) and atropine 0.5 mg (to reduce airway secretions). After 3 minutes of preoxygenation with 100 % FiO_2 via facemask, anesthesia was induced with propofol and rocuronium. A 37-French left-sided double-lumen endotracheal tube was positioned under direct laryngoscopy, with final placement verified by fiberoptic bronchoscopy. Initial one-lung ventilation parameters included a tidal volume of 400 mL, respiratory rate of 16 breaths/minute, and 100 % FiO_2.

The patient developed refractory hypoxemia (SpO_2 85 %) during left single-lung ventilation, necessitating emergent intervention. High-frequency jet ventilation (HFJV) was intermittently administered to the operative right lung through a modified bronchoscopic port. This intervention promptly corrected oxygenation (SpO_2 ↑ 96 % within 30 seconds), establishing a critical window for therapeutic lavage. Currently, the airflow pressure generated by the jet ventilation facilitated efficient perfusion of saline into the alveolar cavities, ensuring that the therapeutic action achieved the desired outcomes (Fig. 3). In total, the right lung was lavaged with 6000 ml of saline at 36 °C. Following sequential saline irrigations, the turbidity of the fluid gradually decreased until clear effluent was obtained, at which point the lavage was completed and thorough suctioning of the right lung segments was performed. Throughout the procedure, oxygen saturation remained stable between 90 % and 96 %, with transcutaneous carbon dioxide levels maintained at 40–50 mmHg. Postoperative arterial blood gas analysis showed a pH of 7.290, elevated PCO_2 (51.08 mmHg), PaO_2 of 72.03 mmHg, base excess of −2.58 mmol/L, and oxygen saturation of 93.6 %. The surgical procedure lasted 180 minutes, with total anesthesia time of 220 minutes. After adequate ventilation, the patient's spontaneous respiration resumed, tidal volume respiratory rate reached the level of extubation, and the bronchial intubation was successfully withdrawn without complaining of any special discomfort, and the patient was transferred back to the ward under medical supervision by specialized personnel.

Following postoperative transfer to the ward, the patient was commenced on heated humidified high-flow nasal cannula (HFNC) oxygen therapy at 45 L/min with an FiO_2 of 60 %. Adjuvant therapy included intravenous methylprednisolone 40 mg daily for anti-inflammatory effects and bronchodilators for reactive airway management. Oxygen support was progressively weaned according to serial arterial blood gas analyses and continuous pulse oximetry, with HFNC discontinued once the patient maintained room air SpO_2 ≥95 % consistently. During the 72-h monitored recovery period, oxygen saturation remained stable (>90 %) without documented

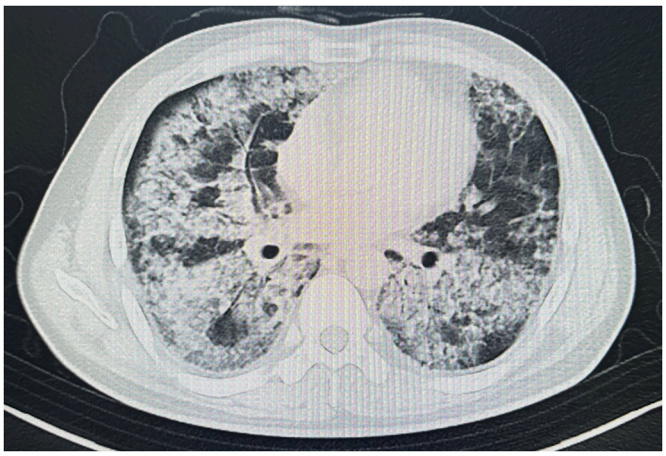

Fig. 1. High-resolution computed tomography (HRCT) examination. There are multiple patchy ground-glass density shadows in the upper lobe of the left lung, localized interlobular septal thickening, and similar patchy ground-glass density shadows in the upper lobe of the right lung. Additionally, there are thickened, reticulated, and lamellar ground-glass density shadows along with patchy shadows in the middle and lower lobes of the right lung as well as in the interlobular septum of the left lung. Multiple grid-like shadows are also present in the subpleural region of both lungs.

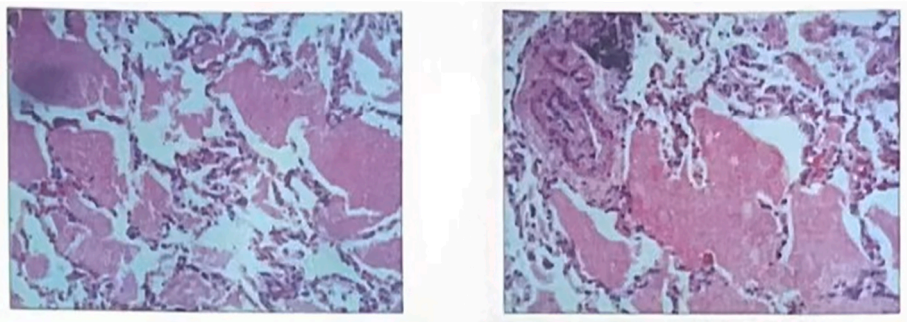

Fig. 2. Transbronchial biopsy histopathology. The pathological report of the lung tissue biopsy revealed eosinophilic, amorphous-like material within certain alveolar cavities. This material tested positive for PAS and IPAS + digestion specific stains.

Fig. 3. The patient is shown with double-lumen bronchial intubation, undergoing intermittent jet ventilation of the lungs involved in the surgical procedure.

episodes of dyspnea or desaturation. The patient was discharged on postoperative day 3 with a room air oxygen saturation of 96 %. A staged contralateral whole-lung lavage (WLL) for the left lung was planned for seven days after discharge.

3. Discussion

Whole-lung lavage (WLL) remains the most effective treatment for pulmonary alveolar proteinosis (PAP) patients with severe hypoxemia [3]. This procedure requires lung isolation for one-lung ventilation. In our case, the patient's PAP resulted in refractory hypoxemia during one-lung ventilation. High-frequency jet ventilation (HFJV) of the lavaged lung demonstrated superior efficacy in rapidly correcting hypoxia compared to both manual ventilation and conventional mechanical ventilation, thereby establishing adequate oxygenation for subsequent lavage procedures. Previous techniques to enhance lavage efficacy have included manual ventilation of the operated lung to distribute saline within alveoli [4] or chest percussion to facilitate protein clearance [5]. In our approach, HFJV served dual purposes: the jet stream effectively delivered saline to distal alveoli while simultaneously mixing the fluid with lipoproteinaceous deposits. This technique optimized therapeutic efficacy while reducing procedural time. The patient achieved satisfactory outcomes without postoperative complications.

High-frequency jet ventilation (HFJV) offers significant advantages in complex airway management by enhancing surgical visibility during procedures requiring shared airway access or precisely controlled ventilation. This technique prolongs critical intervention periods in emergency airway situations through its capacity to maintain adequate oxygenation while reducing diaphragmatic movement. Clinical applications address numerous challenges, including: (1) preoxygenation for anticipated difficult airways, (2) rescue oxygenation during failed intubation attempts, (3) support for single-lung ventilation in cases of severe hypoxemia, and (4) ventilatory assistance during awake thoracic procedures [6].

High-frequency jet ventilation (HFJV) carries several potential complications that clinicians should anticipate: 1) **Barotrauma**: Preventive measures include maintaining an open ventilation system, ensuring adequate expiratory time, strict adherence to HFJV principles, and minimizing traumatic airway maneuvers [7]. 2) **Hypercapnia**: CO_2 retention can be controlled through careful modulation of both driving pressure (to optimize tidal volume) and ventilation frequency [8]. 3) **Gastric insufflation**: Prophylactic nasogastric tube placement is recommended for high-risk patients to prevent gastric distension and elevated intragastric pressures. 4) **Airway mucosal damage**: High gas flow rates may cause mucosal desiccation and hemorrhage, which can be prevented through proper gas warming and humidification [9].

CRediT authorship contribution statement

Renhua Ju: Writing – original draft, Conceptualization. **Xiaonan Du:** Writing – original draft, Data curation. **Ling Yin:** Writing – review & editing. **Yang Yu:** Writing – review & editing, Supervision, Project administration.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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