# High-Frequency Jet Ventilation Rescue of an Off-Pump Single-Lung Transplant

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THE AUTHORS REPORT the successful use of high-frequency jet ventilation (HFJV) during single-lung transplantation (SLTx) in a patient with bullous emphysema-induced inability to achieve adequate ventilation with pressure control ventilation. Jet ventilation improved gas exchange on one-lung ventilation (OLV), allowing for the completion of SLTx while avoiding the use of cardiopulmonary bypass (CPB).

## CASE REPORT

A 64-year-old man weighing 54 kg with smoking-induced end-stage emphysema presented for SLTx. He was dependent on continuous supplemental oxygen at 3 L/min, and his exercise capacity was severely impaired (6-minute walk distance of 180 m, desaturation from 98% to 84% on nasal prongs at 3 L/min, and $\dot{V}o_2$max of 0.52 L/min [24% predicted]). Pulmonary function testing revealed severe obstructive lung disease ($FEV_1$ 0.5 L [17% predicted]; forced vital capacity 2.15 L [58% predicted]; $FEV_1$/forced vital capacity 23% predicted; and DlCO 23% predicted). A room-air arterial blood gas showed significant hypoxemia and moderate $CO_2$ retention (pH of 7.46 mmHg, $pCO_2$ of 52 mmHg, $pO_2$ of 41 mmHg, $HCO_3$ of 38 mmHg, $SaO_2$ of 77%, and A-a gradient of 28.8 mmHg). A chest computed tomography (CT) scan report stated panacinar emphysema; however, the actual images were unavailable at the time of transplant (Figs 1 and 2). A ventilation-perfusion (V/Q) scan exhibited maintained perfusion ratios of 53% and 47% for the right and left lungs, respectively. Transthoracic echocardiography showed normal biventricular size and function, and an absence of valvular pathology. Cardiac catheterization revealed trivial coronary artery irregularities and a slight increase in pulmonary arterial pressures (30/18 mmHg). Cardiac output was calculated at 5.6 L/min (cardiac index, 3.5 L/min/$m^2$). Based on the underlying diagnosis of emphysema, the patient had been listed for single-lung transplantation.

Upon availability of a matching single left donor lung, the patient was prepared for transplantation. In the preoperative area, he was found to be somnolent, only rousing to loud voice or tactile stimulus, which was believed to be secondary to 1 mg of oral lorazepam that the patient had self-administered on learning of the impending transplant. Both a thoracic epidural catheter and radial arterial catheter were placed before the induction of anesthesia. Interestingly, the arterial trace exhibited pulsus paradoxus with a decrease in systolic arterial pressure of 10 to 20 mmHg on spontaneous inspiration, suggesting the presence of significant dynamic hyperinflation secondary to severe emphysema. The intravenous induction with midazolam, 2 mg; fentanyl, 100 $\mu$g; ketamine, 30 mg; and rocuronium, 70 mg; was well tolerated; and a modified 41F right-sided double-lumen tube (DLT; Mallinckrodt/Tyco, Pointe-Claire, Quebec, Canada) was placed without difficulty with the aid of fiberoptic bronchoscopy. Additional invasive catheters and monitors included central venous access with a triple-lumen venous catheter and a venous sheath, an oximetric pulmonary artery catheter, and transesophageal echocardiography (TEE). Anesthesia was maintained with sevoflurane and variable air-oxygen mixtures.

Initial manual ventilation revealed an end-tidal carbon dioxide value of 70 mmHg and surprisingly low lung compliance. Mechanical ventilation was initiated with pressure-controlled ventilation (PCV) at a plateau pressure of 15 $cmH_2O$, a positive end-expiratory pressure (PEEP) level of 5 $cmH_2O$, and a respiratory rate of 10 breaths/min; however, this failed to achieve adequate tidal volumes. Despite an increase in the inspiratory pressure to 22 $cmH_2O$ and a decrease in the respiratory rate to 8 breaths/min, PCV only achieved tidal volumes of 250 mL. Similarly, slow manual ventilation was unable to achieve higher tidal volumes. DLT position was confirmed fiberoptically, which showed patency of the endobronchial tube and all major bronchi. Circuit obstruction or ventilator malfunction was ruled out. Dynamic hyperinflation (DHI) was considered, but temporary disconnection of the ventilatory circuit, allowing for prolonged exhalation, did not result in improved pulmonary compliance.[1] PEEP was discontinued, and the inspiratory:expiratory ratio was set to the ventilator minimum of 1:4. The maintenance of PCV 22/0 $cmH_2O$ achieved tidal volumes of 250 mL at a respiratory rate of 8 breaths/min and was able to maintain end-tidal carbon dioxide levels around 75 mmHg and $SvO_2$ levels of 75% to 80%. Based on mild right ventricular dysfunction on TEE, hemodynamic support with intravenous infusions of milrinone and norepinephrine was initiated. Attempted right-sided OLV was only briefly tolerated, despite ideal positioning of the right DLT (Table 1). PCV 25/0 $cmH_2O$ at a respiratory rate of 8 breaths/min resulted in tidal volumes of 150 mL with a secondary gradual increase in $PaCO_2$ toward 100 mmHg. Despite ongoing hemodynamic support with milrinone and norepinephrine, worsening pulmonary hypertension, progressive right ventricular dysfunction on TEE, and a decrease in continuous $SvO_2$ toward 50% ensued, necessitating resumption of two-lung ventilation.

Since the manipulation of ventilatory parameters, including temporary circuit disconnection, had been unsuccessful in altering pulmonary compliance and static pulmonary tamponade secondary to air trapping in lung bullae was thought to be the primary issue, the authors decided to attempt HFJV for more effective $CO_2$ elimination. CPB was considered the next option, and a primed circuit and perfusionist were on standby in the operating room. Jet ventilation was initiated with an HFJV ventilator (VS600; Instrument Development Corporation, Pittsburgh, PA) via an 8F, 45-cm Airway Exchange catheter (Cook Canada, Stouffville, Ontario, Canada), which had been secured in the bronchial blocker port of an Arndt 3-way adapter (Cook Canada) attached to the

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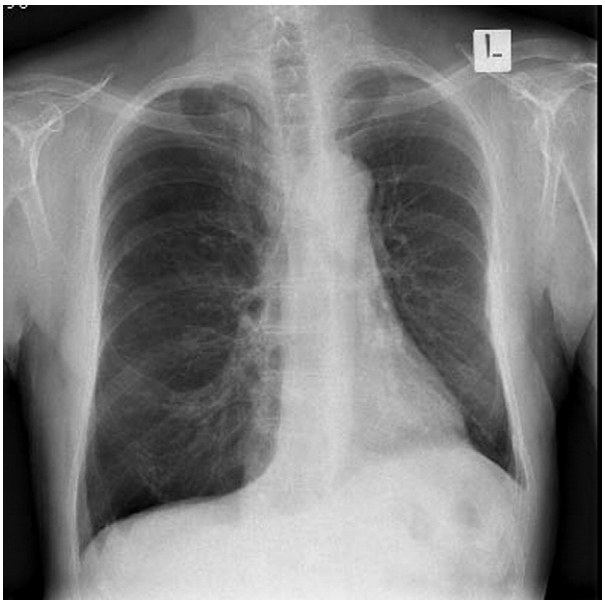

**Fig 1. A preoperative chest radiograph shows severe emphysema with increased radiolucency in the right hemithorax.**

open right endobronchial lumen (Fig 3). Starting settings consisted of 25 psi, rate of 120/min, inspiratory time of 20%, and 100% oxygen. The adequacy of jet ventilation was assessed by initial intermittent conventional ventilation, followed by blood gas analysis. With an increase in the respiratory rate to 140 breaths/min, jet ventilation achieved superior $CO_2$ elimination and a gradual decrease of $PaCO_2$ from 100 to 72 mmHg (Table 1). With the aid of an early pulmonary arterial crossclamp, oxygenation was adequate throughout. Pulmonary arterial pressures remained elevated, but no further episodes of right ventricular failure were evident on echocardiography and the remainder of the transplantation went uneventfully. At reperfusion, the transplanted lung was manually recruited. Taking advantage of the jet ventilator setup, differential ventilation was provided until the conclusion of surgery, with PCV 15/5 $cmH_2O$ and $F_IO_2$ of 0.4 to the transplanted lung and continued jet ventilation to the nonoperative lung. At the conclusion of the procedure, the DLT was exchanged for a 9.0-mm inner diameter Hi-Lo EVAC oral ETT (Nellcor/Tyco, Pointe-Claire) and both lungs ventilated with PCV 20/5 $cmH_2O$, a rate of 15 breaths/min, and an $F_IO_2$ of 0.4, achieving tidal volumes of 350 mL (Table 1). Postoperative chest films showed minimal reperfusion injury to the transplant lung and an unharmed nonoperative lung. Extubation occurred 13 hours after arrival in the ICU, delayed because of iatrogenic overventilation resulting in a loss of respiratory drive. The patient was extubated uneventfully at a $PaCO_2$ of 70 mmHg. He recovered well and was discharged from the hospital on postoperative day 16.

## DISCUSSION

The authors report a patient with severe end-stage emphysema undergoing lung transplantation in whom attempted pressure-control ventilation during one-lung anesthesia failed because of hypoxemia, hypercapnia, and progressive right ventricular failure. HFJV resolved the situation and CPB was avoided. HFJV consists of pulsed delivery of small tidal volumes (2-5 mL/kg) at high frequencies (100-400/min) under pressure.[2] Ventilator settings of driving pressure, frequency, and inspiratory time must be individualized for each patient according to their pulmonary compliance and the proportion of lung segments ventilated.[2] The mechanism of gas exchange is unlike that in conventional ventilation, allowing for tidal volumes that are smaller than the anatomic deadspace. $CO_2$ elimination is possible because of a combination of bulk convection, molecular diffusion, and turbulence of convective flow (Taylor dispersion).[2]

Oxygenation may be improved during HFJV secondary to increased alveolar recruitment and optimal V/Q matching.[3] Overall, gas exchange during HFJV tends to be superior to conventional ventilation.[4] Other advantages of HFJV include lower peak and mean airway pressures compared with conventional ventilation. However, the inability to directly monitor

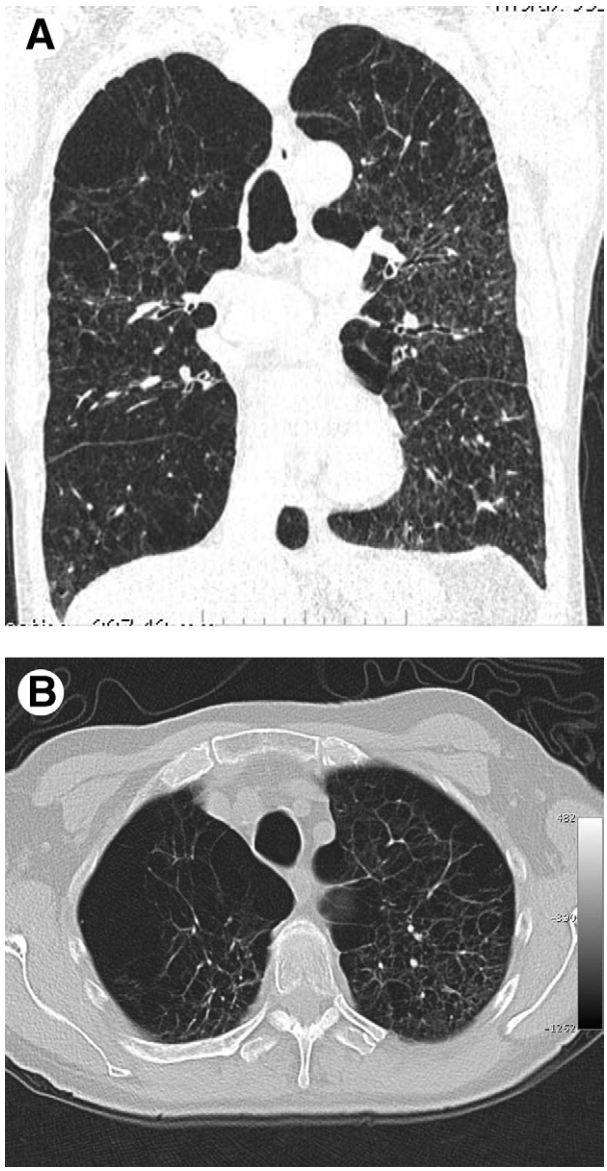


**Fig 2. A preoperative chest computed tomography scan shows severe apical bullous lung disease, with right-sided predominance. CT images were unavailable at the time of the transplant. (A) Coronal and (B) transverse.**