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Postoperative Independent Lung Ventilation in a Single-lung Transplant Recipient

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Transplantation of the human lung was first performed in 1963.[1] Prior to 1978, more than 40 transplants were performed, but the longest survivor lived only 10 months.[2] The major causes of mortality were bronchial dehiscence or respiratory failure due to infection or rejection. Lung transplants are now more successful and more common.[3] Perioperative care of these patients is interesting and challenging for anesthesiologists due to the dramatic hemodynamic and respiratory changes that occur, but there has been little in the anesthesia literature regarding the perioperative care and course of these patients.[4] We report a case of unique perioperative physiology successfully treated with independent lung ventilation in a single-lung transplant recipient.

CASE REPORT

A 50-yr-old woman with advanced pulmonary emphysema due to α_1-antitrypsin deficiency was referred for consideration for single-lung transplantation. The diagnosis of α_1-antitrypsin deficiency had been made at age 32 yr, when she noted exertional dyspnea. At the time of evaluation she was short of breath at rest, could walk only 10 feet without stopping, and used continuous nasal oxygen. She had lost 3.6 kg over the previous 6 months, and now weighed 43 kg; her height was 162 cm.

Preoperative evaluation revealed pulmonary artery pressures of 40 mmHg systolic and 26 mmHg diastolic. Pulmonary capillary wedge pressure was 4 mmHg. Cardiac output was 4.04 $l \cdot min^{-1}$. Pulmonary function tests revealed forced vital capacity 0.96 l (30% of predicted) and FEV_1 0.22 l (9% of predicted). Medications included metaproterenol and ipratropium inhalers. A lung ventilation/perfusion (V/Q) scan revealed multiple bilateral matched ventilation and perfusion defects, with 65% of ventilation and perfusion to the right lung. Arterial blood gas measurements are reported in table 1. The preoperative chest x-ray demonstrated hyperinflation with bullous formation. Other laboratory values were normal.

The patient was brought to the operating room for left lung transplantation. Anesthesia was induced with thiopental 250 mg and fentanyl 250 μg (in divided doses over 5 min), and intubation was facilitated with succinylcholine 100 mg after a defasciculating dose of pancuronium 2 mg. An 8-Fr bronchial blocker catheter with a 20-ml balloon (Fogarty Occlusion Catheter, Baxter model 62-080-8/14F) was placed alongside a 7-mm single-lumen endotracheal tube and was advanced into the left mainstem bronchus with the aid of fiberoptic bronchoscopy to allow selective ventilation of the right lung during the transplantation. A pulmonary artery catheter was inserted after induction and revealed values similar to those measured during the preoperative evaluation. Arterial oxygenation was easily maintained (arterial blood gas [ABG] measurement 3, table 1).

Intermittent doses of ephedrine (5 mg each) and phenylephrine (40–80 μg) were required in order to maintain systolic blood pressure in the 80–100-mmHg range over the 1st h of the surgery, while the surgeons performed the abdominal part of the operation in order to pass a portion of omentum into the thorax with which to "wrap" the eventual bronchial anastomosis.[5] During passage of the omentum, arterial blood pressure decreased to below 50 systolic, necessitating treatment with 300 μg epinephrine and 30–45 s of external cardiac massage. The arterial blood pressure returned to 80–100 mmHg systolic, and dopamine was started at a dose of 7 $\mu g \cdot kg^{-1} \cdot min^{-1}$. A pneumothorax was suspected but could not be demonstrated by the surgeons, and no air was obtained *via* a chest tube. It was noted that if positive pressure ventilation was suspended for short periods (15–45 s), the systolic arterial pressure increased from the 80–90 mmHg range (with dopamine) to 100–110 mmHg. Attempts were made to improve hemodynamics by changing the rate or depth of ventilation at normocapnia, but were not successful.

The anesthesia team made the diagnosis of air-trapping in severely emphysematous lungs causing a decrease in venous return due to a rise in intrathoracic pressure, and deliberate hypoventilation was instituted in an attempt to stabilize the patient's hemodynamics. In an attempt to reduce any bronchospastic contribution to air-trapping, several doses of a metaproterenol inhaler were administered *via* the

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TABLE 1. Arterial Blood Gas Measurements

	Time/Event	FI_{O_2}	pH	Pa_{CO_2} (mmHg)	Pa_{O_2} (mmHg)	Comment
1	Preoperative	RA (0.21)	7.41	52	47	
2	Preoperative	2 l NC	7.40	56	66	
3	Postinduction	1.0	7.42	46	421	Tidal volume ≈ 500 × 10/min
4	Deliberate hypoventilation (intraoperative)	1.0	7.29	69	411	Tidal volume ≈ 400 × 3–6/min
5	Right-lung ventilation (intraoperative)	1.0	7.31	66	554	Left PA and bronchus clamped
6	Initial postoperative (DLT)	0.5	7.32	52	286	Right: 200 ml × 4/min Left: 500 ml × 20/min
7	POD 1 (24 h postoperative)	0.4	7.44	43	116	Right: 250 ml × 6/min Left: 450 ml × 15/min
8	POD 1 (25 h postoperative); single-lumen tube	1.0	7.28	61	53	750 ml × 12/min
9	POD 1 (26 h postoperative)	1.0	7.30	57	178	Right: 250 ml × 4/min Left: 400 ml × 16/min
10	POD 6 (after extubation)	4 l NC	7.30	55	158	
11	3 months postoperative	RA	7.46	35	92	

DLT = double-lumen tube (right-sided); NC = nasal cannula; PA = pulmonary artery; POD = postoperative day; RA = room air; SLT = single-lumen endotracheal tube; V_T = tidal volume.

endotracheal tube, with no obvious improvement. For the rest of the operation, including during one-lung ventilation, the respiratory rate was kept at 3–6 breaths per min (tidal volume ~400 ml) with the arterial carbon dioxide tension in the 60–80-mmHg range. This maneuver succeeded in maintaining acceptable hemodynamics. No potent volatile anesthetics were administered from this point on in the surgery, and the anesthetic consisted mainly of intermittent doses of fentanyl (1–5 μg/kg).

When the left chest was opened, the diagnosis of air-trapping in both right and left lower lobes was confirmed visually. The surgeons reported that the lungs, especially the lower lobes, were exceedingly "tense" due to hyperinflation. With the patient in the right lateral decubitus position and only the right lung ventilated, the mediastinum could be seen to rise with each breath and not to return to a neutral position until 10–20 s of apnea. When a respiratory rate of 10 breaths per min was instituted, the mediastinum shifted progressively toward the left chest, reflecting right lung overexpansion, and the blood pressure decreased. Hypoventilation was resumed and was well-tolerated (ABG 4, table 1). The left-lung transplantation was performed uneventfully.

After implantation of the new left lung, ventilation of both lungs resulted in preferential expansion of the native right lung. A 37-Fr right-sided tube double-lumen endotracheal tube was placed at the end of surgery in order to maintain differential ventilation of the two lungs for postoperative ventilatory management. A right-sided tube was chosen in order to avoid the left bronchial anastomosis, accepting the possibility of hypoventilation or collapse of the right upper lobe, especially since deliberate hypoventilation of the right lung was planned in any case. The patient was transferred to the intensive care unit (ICU) with only the left lung ventilated and with the pulse oximeter confirming hemoglobin oxygen saturation of 100%.

In the ICU, two ventilators were used, with initial settings of: right lung, 200 ml × 4 per min; left lung, 500 ml × 20 per min; and fractional inspired oxygen concentration 0.5 (ABG 6, table 1). These initial settings, with occasional minor manipulation, were typical of the ventilatory settings used in the ICU during the period of independent lung ventilation. The initial postoperative chest x-ray is shown (figure 1), with the right-sided double lumen endobronchial tube in place. The patient did well for the first 24 h (ABG 7, table 1). At that time, in an attempt to discontinue independent lung ventilation, the trachea was reintubated with a single-lumen endotracheal tube, while mechanical ventilation was maintained. Over the first minutes, the patient did well, but after 15–20 min she became agitated, and the oxygen saturation (percent) on the pulse oximeter decreased from the high 90s to the mid-80s (ABG 8, table 1). A chest x-ray obtained at that time showed overexpansion of the right lung and displacement of the left lung and heart (fig. 2). A right-sided double-lumen endobronchial tube was replaced, with improvement in oxygenation (ABG 9, table 1). A chest x-ray 2 h after this episode, with the right-sided tube again in place, revealed the right lung overexpansion resolved (Figure 3). The lungs were ventilated in the manner described above until postoperative day 6, when the trachea was extubated and the patient was doing well (ABG 10, table 1). She was discharged from the hospital about 4 weeks later. There have been no further postoperative complications during the 1 yr since discharge, the patient has done has resumed a normal, active lifestyle. She recently exercised for 33 min on a treadmill at an estimated workload of 4 metabolic equivalent system units ([METS] where 1 MET = resting oxygen consumption [3.5 $ml \cdot kg^{-1} \cdot min^{-1}$]) without arterial desaturation or subjective dyspnea while breathing room air (ABG 11, table 1).

DISCUSSION

Either of the major pulmonary pathophysiologic processes, restrictive (fibrotic) or obstructive lung disease, may lead a patient to be a candidate for lung transplantation. In general, single-lung transplantation has been advocated for patients with pulmonary fibrosis[5]; double-lung transplantation for patients with chronic obstructive pulmonary disease (COPD) or cystic fibrosis[6,7]; and heart–lung transplantation for patients who need a lung transplantation and also have evidence of right ventricular failure.[3] Single-lung transplantation for COPD was attempted in the 1960s, but there were no long-term survivors. Stevens *et*

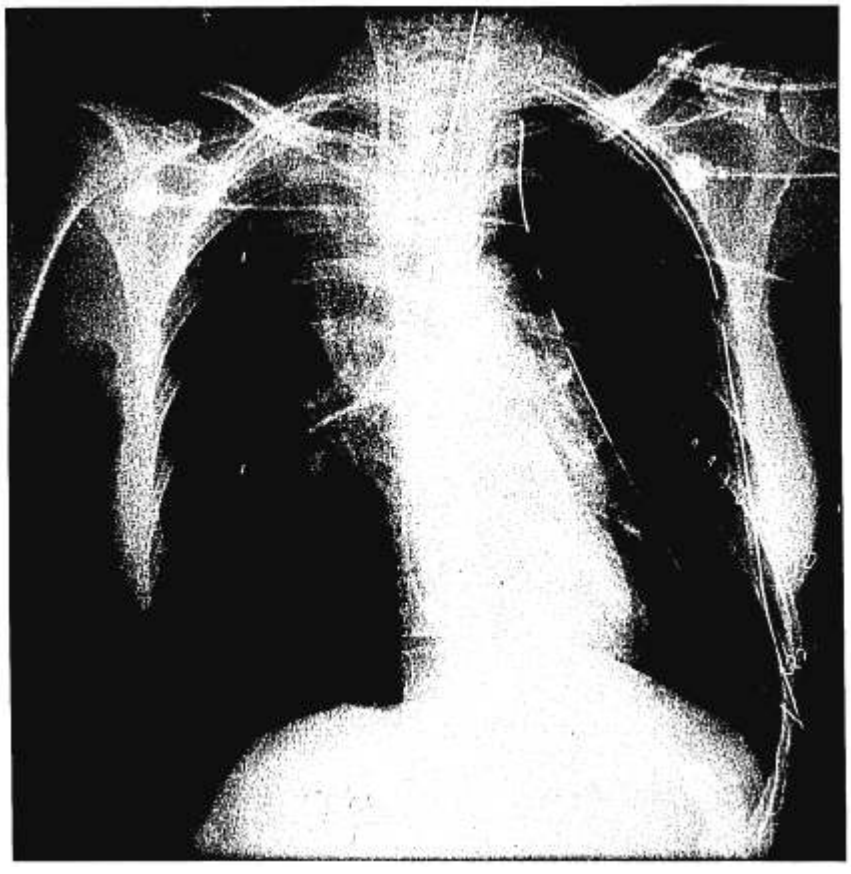

FIG. 1. Immediate postoperative portable frontal radiograph of chest. A right-sided double lumen endobronchial tube extends down the right main bronchus, and the right upper lobe is collapsed.

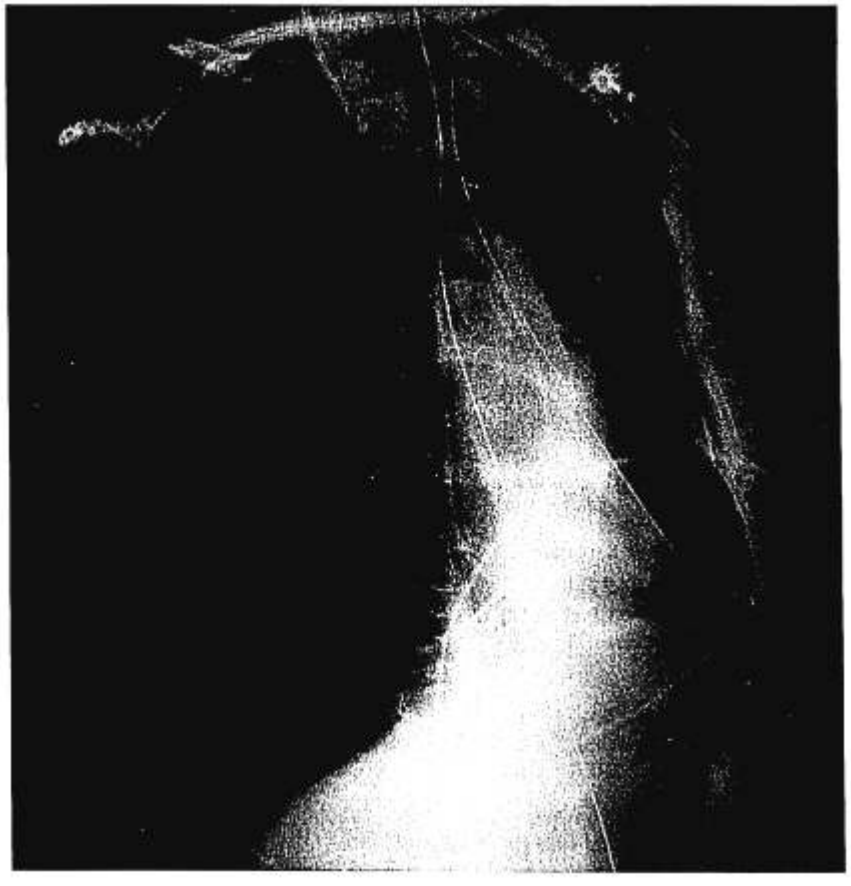

FIG. 2. Radiograph taken on 2nd postoperative day, 15 min after removing double-lumen tube and replacing with single-lumen tube. The right (native) lung is massively hyperinflated, displacing the left lung and heart.

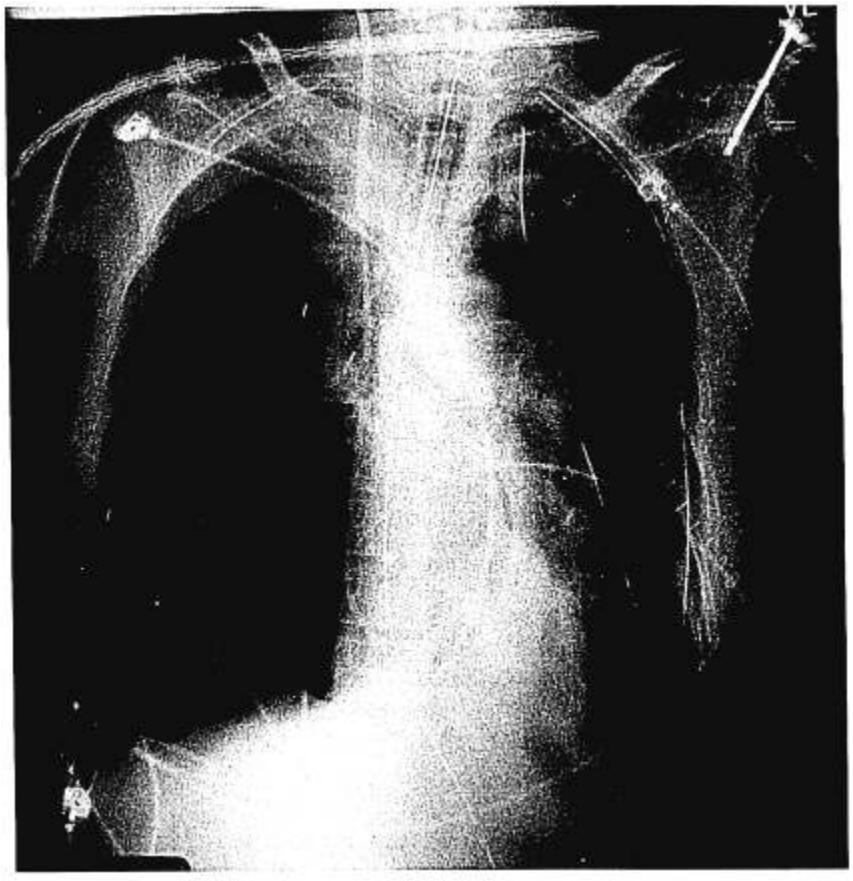

FIG. 3. Radiograph 2 h after replacement of right-sided tube and reinstitution of independent lung ventilation with deliberate hypoventilation of the right lung, with resolution of right-lung hyperinflation (and reappearance of right upper lobe collapse).

al.[8] and Vanderhoeft *et al.*[9] reported cases of unsuccessful single-lung transplantation in patients with emphysema and suggested that the respiratory failure seen postoperatively was due to the creation of a system in which the native lung has low elastic recoil and increased vascular resistance, connected in parallel with a transplanted lung with greater recoil, resulting in preferential ventilation of the native lung and a substantial V/Q mismatch. Wildevuur and Benfield, in a review of the first 23 human lung transplantations, suggested that this problem was common in transplantations performed for COPD.[10] In a recent report on single-lung transplantation for pulmonary fibrosis, Grossman *et al.* suggested that transplantation might be unsuitable for patients with obstructive lung disease due to possible postoperative V/Q inequalities.[11] Sleiman *et al.*[12] disagreed with this assertion, and reported no significant postoperative V/Q imbalance in eleven patients transplanted for emphysema. Veith *et al.* have presented evidence that part of the cause of V/Q mismatch may be rejection or some other process in the transplanted lung, and suggested that single-lung transplantation may be appropriate in emphysema.[13]

Recent reports support the view that many patients with emphysema may do well with a single-lung transplantation.[14–16] We have performed single-lung transplantation in three other patients with emphysema over the past year, without the above-described problem. These patients had less severe bullous disease, and none had α_1-antitrypsin deficiency. It may be that the presence of severe bullous disease predisposes to more extensive air-trapping and substantial V/Q mismatching after transplantation, or it may be that α_1-antitrypsin deficiency emphysema behaves somewhat differently than other, more typical forms of the disease.

Compromise of cardiac function and hemodynamics by mechanical ventilation is a well-described phenomenon, particularly when positive end-expiratory pressure (PEEP) is used.[17] Air-trapping in this patient's native lung may have functioned much like PEEP in decreasing venous return by increasing intrathoracic pressure. Attempts to minimize this problem by altering the ventilatory settings to maximize expiratory time and decrease tidal volumes were unsuccessful. Independent lung ventilation has been reported to be useful in clinical situations involving unilateral lung disease or major differences in lung compliance, including bronchopleural fistula, unilateral pneumonia or pulmonary edema, trauma (surgical or otherwise), hemorrhage, and other causes.[18–23] In this case, the preferential ventilation of the native, high-compliance, emphysematous lung was prevented by setting the ven-

tilators to deliver larger volumes and more frequent breaths to the transplanted lung. No attempt was made to synchronize the ventilators, as this did not appear to be necessary, perhaps because the native lung was being significantly hypoventilated. In some cases of independent ventilation, ventilators have been synchronized, but the need for this has been questioned, and no study has demonstrated that synchronous ventilation has an advantage over random split ventilation.[24] Complications of independent lung ventilation may include laryngeal, tracheal, or bronchial trauma from the required double-lumen tube, which is substantially larger than a regular endotracheal tube. Inadequate ventilation due to misplacement or anatomic anomalies also may occur. In this patient, there was some collapse of the right upper lobe during the postoperative period, as might be expected given the known difficulty in maintaining right-sided double-lumen tube position.[25]

In this case, alternative treatments to independent lung ventilation were jet or high-frequency ventilation, or even a pneumonectomy on the right side, but these were not attempted, since the patient was tolerating the differential ventilation well and since her general condition did not warrant changing a successful strategy. Apparently, the differential compliance of the two lungs is not as significant a problem when this patient breathes spontaneously, for she has done extremely well after extubation and discharge from the hospital. No laryngeal or tracheal complications have been noted from the prolonged intubation with the rather large double-lumen endobronchial tube.

In summary, a single (left)-lung transplant was successfully performed on a patient with end-stage emphysema resulting from α_1-antitrypsin deficiency. Evidence of severe air-trapping in the emphysematous lung(s) was treated intraoperatively with deliberate hypoventilation, and prevention of air-trapping and prevention of preferential ventilation of the highly compliant native lung was accomplished postoperatively with the use of a right-sided double-lumen endobronchial tube and differential ventilation of the two lungs. This strategy may be useful postoperatively in selected patients with obstructive pulmonary disease undergoing single-lung transplantation.

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