Potential for detrimental hyperinflation after lung transplantation with application of negative pleural pressure to undersized lung grafts

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In our program, postoperative lung recipients are temporarily maintained on positive-pressure ventilation, with suction routinely applied to the thoracostomy tubes. We have occasionally seen negative pleural pressure applied to a large pleural space alter the respiratory mechanics of lung allografts and contribute to primary graft failure. We hypothesize that the combination of undersized lung grafts and negative pleural pressure may inhibit the lung's elastic recoil and lead to detrimental hyperinflation. If alveoli decompress incompletely during exhalation, functional residual capacity increases, and subsequent mechanical ventilations are delivered to partially distended lungs. After several stacked breaths, lungs hyperinflate and operate on a flatter portion of the volume-pressure curve. During volume-cycled ventilation, this manifests as increased airway pressure, with an increased potential for barotrauma. We prospectively studied this phenomenon after bilateral lung transplantation.

Methods

Consent was obtained from the patients, and the study was approved by the human studies committee. Twenty-four bilateral lung transplant recipients were studied between July 17, 2001, and April 9, 2002. Transplant indications included emphysema ($n = 16$), cystic fibrosis ($n = 6$), idiopathic pulmonary fibrosis ($n = 1$), and lymphangioleiomyomatosis ($n = 1$). Patients were evaluated within 6 hours of reperfusion while they were receiving mechanical ventilation at a tidal volume of 10 mL/kg (volume-cycled ventilation). Thoracostomy tubes were placed to atmospheric pressure for at least 2 minutes to allow system stabilization before the following parameters were measured: tidal volume, peak and plateau airway pressures, compliance, heart rate, and pulmonary arterial and systemic blood pressures. Thoracostomy tubes were then connected to suction (-20 cm H₂O) for 2 minutes before repetition of the measurements.

We evaluated the collective effects on these parameters measured in the setting of negative versus atmospheric pleural pressure. Statistical analysis was performed with the Student *t* test with

TABLE 1. The effects of pleural pressure on respiratory mechanics and hemodynamics after bilateral lung transplantation

Variable	Atmospheric pleural pressure	Negative pleural pressure	<i>P</i> value
Peak airway pressure (cm H ₂ O)	33 ± 12	38 ± 11	.02
Plateau airway pressure (cm H ₂ O)	28 ± 9	32 ± 9	.05
Compliance (mL/cm H ₂ O)	31 ± 12	27 ± 12	.04
Exhaled tidal volume (mL)	820 ± 241	800 ± 240	.11
Heart rate (beats/min)	92 ± 23	96 ± 15	.37
Mean pulmonary arterial pressure (mm Hg)	16 ± 5	17 ± 5	.2
Mean systemic blood pressure (mm Hg)	82 ± 14	82 ± 12	.91

Data are reported as the mean ± SD for 24 patients after bilateral sequential lung transplantation. Negative pleural pressure significantly increased airway pressures and reduced compliance for this group of 24 patients ($P < .05$).

a Dunn-Sidak adjustment for multiple *t* tests. The transplant recipient total lung capacity was obtained from the last set of pulmonary function tests obtained before transplantation. The donor total lung capacity was estimated from the donor height and age with a standard nomogram.¹

Results

When the 24 patients were evaluated collectively, negative pleural pressure significantly ($P \leq .05$) increased airway pressures and reduced compliance relative to atmospheric pleural pressure (Table 1). Three patients who received transplants for emphysema demonstrated dramatic adverse responses to negative pleural pressure. Negative pleural pressure increased their peak airway pressures by 135%, 108%, and 93%, whereas their compliances decreased by 66%, 71%, and 53%, respectively (Table 2).

Measurements were repeated three times with consistent results. A scattergram showing the relationship between the actual recipient total lung capacity and the calculated donor total lung capacity is provided in Figure 1. The diagonal line of unity divides the plot into two groups, those with graft lungs smaller than the pleural space and those with graft lungs larger than the pleural space. All 3 adverse responses to negative pleural pressure occurred in patients in whom the lungs were smaller than the pleural space.

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Figure 1. Scattergram shows relationship between measured recipient total lung capacity (TLC) and estimated donor total lung capacity in 24 lung transplant operations. *Circles* represent patients without evidence of reduced compliance in presence of negative pleural pressure; *triangles* represent patients with dramatic response to pleural suction.

TABLE 2. The effects of negative pleural pressure on 3 patients undergoing transplantation for emphysema

	Peak airway pressure (cm H ₂ O)		Plateau airway pressure (cm H ₂ O)		Compliance (mL/cm H ₂ O)	
	Atmospheric	Negative	Atmospheric	Negative	Atmospheric	Negative
Patient 1	21	49	17	48	35	12
Patient 2	24	50	22	49	38	11
Patient 3	15	29	12	26	41	19

Negative pleural pressure dramatically increased the airway pressures and reduced the compliance in three patients transplanted for emphysema. Measurements were repeated 3 times and the results were consistent. Thoracostomy tubes were taken off suction and left at atmospheric pressure during positive pressure ventilation.

Discussion

Thoracostomy tubes are frequently placed to suction after lung transplantation to facilitate the removal of intrapleural air and fluid. However, negative pleural pressure may have a detrimental effect on patients who receive relatively undersized lungs. A total of 1035 lung transplants were performed in North America in 2000, with the most common indication being emphysema or chronic obstructive pulmonary disease (40.6%).² Patients with emphysema, along with recipients of living related lobar transplants, are at greatest increased risk for receiving undersized allografts. If this occurs, chest wall compliance offers less restriction on lung volume. Negative pleural pressure may counteract the lung's elastic recoil, promoting alveolar hyperinflation within the enlarged pleural space.

Lung hyperinflation during mechanical ventilation can produce stress fractures in alveoli and pulmonary capillaries, resulting in pulmonary edema.³ Similarly, hyperinflation of lung grafts during cold storage also increases endothelial permeability.⁴ This phenomenon may have significance for aspects of pulmonary pathophysiology other than transplantation. In cases of postpneumectomy edema, increased blood flow and catecholamine release may increase endothelial permeability in the remaining lung, creating a microvascular environment analogous to that seen in reperfused allograft lungs.⁵ Furthermore, suction applied to the postpneumectomy space may induce hyperinflation of the remaining lung and reduce perivascular hydrostatic pressure and further promote pulmonary edema.⁶

This study was designed to prospectively evaluate a phenomenon that we have observed intermittently during the past few years. Negative pleural pressure dramatically increased airway pressures and reduced lung compliance in 3 patients who underwent transplantation for emphysema. In this small series, the incidence of this phenomenon among patients with emphysema was 3 of 16 (19%, 70% confidence interval 6%-39%). Theoretically, patients with cystic fibrosis receiving living related lobar transplants are at even greater risk for this phenomenon. Lobar grafts are usually undersized, and patients with cystic fibrosis usually have a hyperexpanded thoracic cavity. The calculation of donor total lung capacity in this study was imprecise and based only on the donor age and height. We do not make such a calculation in clinical practice, and this part of the analysis was performed only for the purposes of better understanding these observations.

In conclusion, negative pleural pressure in an enlarged pleural space may induce hyperinflation of the transplanted lung and contribute to primary graft failure. A potential solution is to normalize pleural pressure during mechanical ventilation with an empty water seal chamber in the chest bottles or in standard devices such as the Pleur-Evac (Deknatel, Inc, Fall River, Mass). Any chest drainage device that is disabled by not filling the water seal will behave like an open pneumothorax during the exhalation phase of mechanical ventilation. This will prevent the stacking of breaths and should make the described phenomenon impossible. It is obviously important that the water seal chamber be filled at the

precise moment of extubation to avoid a true open pneumothorax in an extubated patient. We currently test all recipients of undersized lungs and avoid the combination of pleural suction and positive-pressure ventilation if patients demonstrate any evidence of breath stacking.

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Resection of anterior mediastinal tumor through a ministernotomy: Preliminary experience with ten cases

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Various minimally invasive surgical approaches have recently been proposed for the management of valvular heart disease^{1,2} and of myasthenia gravis related to thymic hyperplasia.^{3,4} In this report we review our preliminary experience of anterior mediastinal tumor resection through a ministernotomy.

Patients

Since October 2000, a total of 10 patients (6 men and 4 women, mean age 5 years, range 19-73 years) underwent surgical resection through a ministernotomy of a suspected anterior mediastinal tumor or mass measuring less than 7 cm on computed tomographic (CT) scan. The characteristics of all patients and tumor findings are presented in Table 1.

Surgical Technique

The opening technique was the same as that for aortic and mitral valve operation, a technique that has been previously described in our department by Massetti and colleagues.² In brief, a midline skin incision (6-7 cm long) was made according to the location of

Figure 1. Skin incision of patient 9 on fourth postoperative day.

the lesion or tumor visible on CT scan, generally going from the second to the fourth interspace or from the third to the fifth interspace. In all cases the incision was clearly less than half of the length of the sternal bone. The skin and subcutaneous tissue were dissected, and a median sternotomy (manubrium and body) was carried out with a sagittal saw (Zimmer Micro 100; Linvatec, Largo, Fla); the portion of the sternum under the skin flap (cephalad and caudal) was easily divided with the aid of an illuminating disposable retractor (USSC Mini Harvest; United States Surgical Corporation, Norwalk, Conn). Once the thoracic retractor (such as a Tuffier device) was inserted, the spreading of the two sternal edges was limited to 5 to 6 cm. The section of the sternal bone ended at the xiphoid appendage, which was preserved. According to Port and Ginsberg,⁵ all surgical principles for resection of mediastinal tumors were strictly respected; that is, en bloc resec-

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