CHEST

Transpleural Ventilation via Spiracles in Severe Emphysema Increases Alveolar Ventilation

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In emphysema airway resistance can exceed collateral airflow resistance, causing air to flow preferentially through collateral pathways. In severe emphysema ventilation through openings directly through the chest wall into the parenchyma (spiracles) could bypass airway obstruction and increase alveolar ventilation via transpleural expiration. During lung transplant operations, spiracles occasionally can occur inadvertently. We observed transpleural expiration via spiracles in three subjects undergoing lung transplant for emphysema. During transpleural spiracle ventilation, inspiratory tidal volumes (TV) were unchanged; however, expiration was entirely transpleural in two patients whereas the expired TV to the ventilator circuit was reduced to 25% of the inspired TV in one. At baseline, mean PCO_2 was 61 ± 5 mm Hg, which decreased to a mean PCO_2 of 49 ± 5 mm Hg ($P = .05$) within minutes after transpleural spiracle ventilation and further decreased at 1 to 2 h (36 ± 4 mm Hg; $P = .002$ compared with baseline) on unchanged ventilator settings. This observation of increased alveolar ventilation supports further studies of spiracles as a possible therapy for advanced emphysema. CHEST 2016; 149(6):e161–e167

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Collateral ventilation is defined as ventilation of alveolar structures through passages or channels that bypass the normal airways.[1] In supine normal subjects at the end of a quiet expiration, resistance to airflow is greater through collateral channels than through bronchi and bronchioles.[1] In emphysema, however, airway resistance can exceed collateral resistance, causing air to flow preferentially through collateral pathways.[1,2] In an accompanying editorial, Macklem[3] stated, "… if collateral flow resistance is less than airway resistance …ventilation … through openings directly through the chest wall into the parenchyma should bypass the obstruction, decrease work of breathing,

ABBREVIATIONS: ABG = arterial blood gas; HB_{pred} = predicted resting energy expenditure equation; LTx = lung transplant; MV = minute ventilation; PEEP = positive end-expiratory pressure; PIP = peak inspiratory pressure; PPF = parenchymal-pleural fistula; RR = respiratory rate; RV = residual volume; TVexp = expired tidal volume; TVinsp = inspired tidal volume; VA = alveolar ventilation; VCO_2 = estimated CO_2 production calculated from Harris-Benedict equation; Vd/Vt = estimated dead-space fraction

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increase alveolar ventilation and improve dyspnea. Insects breathe through openings on their body surface … called spiracles."

To the best of our knowledge, there are no in vivo human data testing the spiracle hypothesis that ventilation through openings directly through the chest wall into the parenchyma could bypass airway obstruction and increase alveolar ventilation in severe emphysema. During the lung transplant (LTx) operation in patients with severe emphysema, lung spiracles can occur when the pleura or parenchyma is punctured inadvertently during dissection from the chest wall, and we previously described complete transpleural exhalation.[4] In this case series we describe that transpleural spiracle ventilation reproducibly and significantly increases alveolar ventilation and CO_2 elimination in subjects undergoing bilateral LTx for severe emphysema during mechanical ventilation of the native lungs.

Methods

The data for this study were collected intraoperatively during the LTx of three patients with severe emphysema; it is a retrospective review of the collected data. At the University of Iowa LTx Program a transplant pulmonologist is present in the operating room for all LTx operations. From February 1, 2015 to June 1, 2015, the transplant pulmonologist monitored intraoperative inspired tidal volumes (TVinsp) and expired tidal volumes (TVexp) to identify the occurrence of transpleural spiracle ventilation (TVexp < 50% of TVinsp) during intraoperative native lung mechanical ventilation of subjects undergoing a bilateral LTx for emphysema. The transplant pulmonologist obtained photos from the anesthesia ventilator monitor to document the occurrence of transpleural spiracle ventilation. There were no study interventions or study specific measurements and the LTx and anesthesia occurred via routine clinical care (Fig 1). We obtained consent from subjects included in this case series to review the medical record and reproduce the obtained photos of the ventilator monitor. We retrospectively extracted and analyzed data that were obtained via routine clinical care for the subjects for whom transpleural spiracle ventilation had occurred. For periods of ventilation of both native lungs, we reviewed ventilator settings, airway pressures (peak inspiratory pressure [PIP] and positive end-expiratory pressure [PEEP]), TVinsp, TVexp, and arterial blood gas (ABG) measurements (Fig 1). We estimated dynamic respiratory system compliance as TVinsp / (PIP - PEEP). We calculated minute ventilation (MV) as respiratory rate (RR) multiplied by TVinsp (RR × TVinsp). Alveolar ventilation (VA) was estimated based on the alveolar CO_2 equation (Equation 1):

$$\text{Partial pressure of carbon dioxide}\,(PaCO_2) = (VCO_2 \times 0.863)/VA \quad (1)$$

and VA was calculated as (Equation 2):

$$VA = (VCO_2 \times 0.863)/PaCO_2 \quad (2)$$

where VCO_2 is the estimated CO_2 production calculated from the Harris-Benedict[5,6] equation (Equation 3):

$$VCO_2 = (HB_{pred} \times 0.8)/6.8644 \quad (3)$$

HB_{pred} is the predicted resting energy expenditure equation and is sex specific (Equations (4) and (5)):

$$\text{For females, } HB_{pred} = 655.1 + (6.56 \times \text{weight [kg]}) + (1.85 \times \text{height [cm]}) - (4.56 \times \text{age})^5 \quad (4)$$

$$\text{For males, } HB_{pred} = 66.45 + (13.75 \times \text{weight [kg]}) + (5 \times \text{height [cm]}) - (6.76 \times \text{age})^5 \quad (5)$$

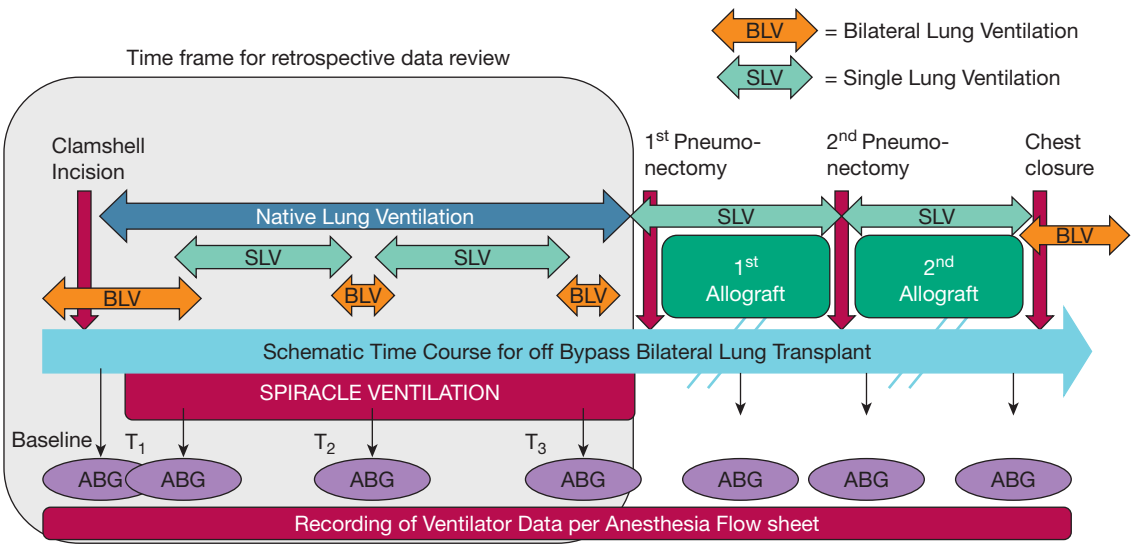

Figure 1 – *Schematic overview of time period and data elements obtained during routine clinical care that were available for retrospective review in subjects in whom transpleural spiracle ventilation occurred during a bilateral lung transplant for emphysema. T_1: Within 5 to 10 min of the onset of transpleural spiracle ventilation. T_2: Approximately 1 to 2 h after the onset of transpleural spiracle ventilation. T_3: Approximately 2 to 3 h after the onset of transpleural spiracle ventilation. ABG = arterial blood gas.*