INDEPENDENT LUNG VENTILATION

SUMMARY

Independent Lung Ventilation (ILV) is a rare and technically demanding procedure for managing unilateral lung disease or injury in patients who have failed conventional modes of mechanical ventilation. No controlled clinical trials of ILV exist**,** but multiple case reports have shown it to be a viable option as a rescue ventilator strategy when conventional mechanical ventilation strategies have failed. In select critically ill patients, ILV can significantly improve aeration of collapsed alveolar segments, increase systemic oxygenation, reduce hypoventilation, and reduce intrapulmonary shunt fraction. While the need to apply ILV is rare, it is a skill with which all physicians who manage the critically ill should be familiar.

RECOMMENDATIONS

Level 1

- **None**

Level 2

- **None**

Level 3

- **ILV should be considered in the patient with radiographically apparent unilateral lung disease and one or more of the following:**
  - **Hypoxemia refractory to high FiO_2 and positive end-expiratory pressure (PEEP)**
  - **PEEP-induced deterioration in oxygenation or shunt fraction**
  - **Overinflation of the noninvolved lung with or without collapse of the involved lung**
  - **Significant deterioration in circulatory status in response to PEEP**
  - **For anatomical separation in cases of unilateral endobronchial bleeding until definitive repair can be performed**
  - **To protect the bronchial repair after traumatic bronchial injury**
- **ILV should be considered in the patient with bronchopleural fistula (BPF) who demonstrates one or more of the following:**
  - **Air leak exceeding 50% of the delivered tidal volume**
  - **Hypercapnic respiratory acidosis (pH<7.30)**
  - **Refractory hypoxemia particularly in patients in whom increases in PEEP exacerbate air leak**
  - **Persistent lung collapse despite optimum catheter drainage**
- **Invasive hemodynamic monitoring is frequently advisable to monitor the effect of ILV on cardiac output and intrapulmonary shunt.**

INTRODUCTION

Acute lung injury (ALI) and acute respiratory distress syndrome (ARDS) are characterized by regions of normal, compliant lung adjacent to areas of abnormal, atelectatic, non-compliant lung. Recruitment of

EVIDENCE DEFINITIONS

- **Class I:** Prospective randomized controlled trial.
- **Class II:** Prospective clinical study or retrospective analysis of reliable data. Includes observational, cohort, prevalence, or case control studies.
- **Class III:** Retrospective study. Includes database or registry reviews, large series of case reports, expert opinion.
- **Technology assessment:** A technology study which does not lend itself to classification in the above-mentioned format. Devices are evaluated in terms of their accuracy, reliability, therapeutic potential, or cost effectiveness.

LEVEL OF RECOMMENDATION DEFINITIONS

- **Level 1:** Convincingly justifiable based on available scientific information alone. Usually based on Class I data or strong Class II evidence if randomized testing is inappropriate. Conversely, low quality or contradictory Class I data may be insufficient to support a Level I recommendation.
- **Level 2:** Reasonably justifiable based on available scientific evidence and strongly supported by expert opinion. Usually supported by Class II data or a preponderance of Class III evidence.
- **Level 3:** Supported by available data, but scientific evidence is lacking. Generally supported by Class III data. Useful for educational purposes and in guiding future clinical research.

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these areas of alveolar collapse is essential to improving systemic oxygenation and reducing intrapulmonary shunt fraction (Qs/Qt). This is typically accomplished using conventional mechanical ventilation, a single-lumen endotracheal tube, and appropriate utilization of both tidal volume and positive end-expiratory pressure (PEEP).

When pulmonary injury is severe and primarily one-sided, conventional lung ventilation (i.e., treating both lungs as a single, homogeneous unit) can be ineffective. Such disease processes include significant unilateral pulmonary contusion or aspiration pneumonia, bronchopleural fistula (BPF), massive unilateral pulmonary embolism, or single-lung transplant. The majority of the delivered minute ventilation enters the normal, compliant lung, potentially exposing alveoli to overdistention, increased shear forces, and volutrauma (commonly inappropriately referred to as "barotrauma") while the stiff, collapsed lung receives a progressively smaller portion of the total ventilation (1). This initiates a vicious cycle whereby the injured alveoli are not recruited, but rather collapse further, leading to worsening compliance, oxygenation, and ventilation. This oxygen refractory process may proceed to the point that ventilation of either a portion of or an entire lung may become impossible.

Selective or "independent" lung ventilation (ILV) outside of the operating room was first reported in the 1970s as a methodology by which to more efficiently match perfusion and ventilation of asymmetrically injured lungs. This ventilatory technique, requiring a double-lumen endotracheal tube and two mechanical ventilators, is a technically demanding procedure for managing unilateral lung disease (ULD) in patients who have failed conventional modes of mechanical ventilation. ILV can significantly improve aeration of collapsed alveolar segments, increase systemic oxygenation, reduce hypoventilation, and reduce Qs/Qt.

Traumatic BPF represents an especially difficult ventilatory management problem. Once the alveolar wall has been disrupted, large tidal volumes delivered by positive pressure ventilation allow air to pass into the bronchoalveolar sheath and root of the lung from which air may enter the pleural space and result in pneumothorax. While potentially lifesaving, tube thoracostomy to drain the pneumothorax allows a continuous leak of air from the tracheal tree to the external world. The resulting loss of airway pressure leads to progressive alveolar collapse. The traditional treatment for ALI and ARDS (increased tidal volumes and PEEP) may only serve to worsen the magnitude of the fistula. BPF management should therefore focus upon decreasing airway pressure and minimizing pleural suction to decrease the air leak and promote healing. Weaning from positive pressure ventilation and avoidance of alveolar hyperinflation are most advantageous in decreasing the air leak. ILV has been reported by numerous authors as one method by which to restore alveolar volume and oxygenation as well as promote healing of a BPF (1-6).

Given the rare need for its application, there are no controlled clinical trials of ILV nor clear-cut indications for its use. The great majority of patients with ALI and ARDS, even if primarily unilateral, can be successfully managed using conventional ventilatory techniques. In traumatic injuries leading to unilateral lung hemorrhage, ILV may also be used as a temporizing measure to prevent blood from spreading to healthy lung until the damaged lung can be repaired surgically (7). While the need to apply ILV is unusual, it is a skill with which all physicians who manage the critically ill should be at least somewhat familiar. The acutely decompensating, hypoxic patient with ULD rarely affords a physician sufficient time to learn and apply this technically demanding, labor-intensive, and potentially hazardous procedure.

MANAGEMENT

Although a variety of techniques for ILV have been described, a complete discussion on this subject is outside the scope of this document. The purpose of this guideline is to familiarize the reader with a safe and reasonable approach to effectively ventilating and oxygenating the patient with ULD who has failed conventional methods of mechanical ventilation.

Obtaining and Maintaining Lung Separation

ILV requires selective control of each mainstem bronchus. Without such separation, both lungs will continue to be treated as a single unit. ILV may be classified into two methods based upon the intended lung separation endpoint.

Anatomical separation is necessary to protect a normal lung from injury or contamination by the diseased lung. Indications for anatomical separation include massive hemoptysis, whole lung lavage, lung abscess, or copious pulmonary secretions (3,5). Typically a short-term emergent intervention to maintain oxygenation and ventilation until definitive therapy can be performed, anatomical separation is usually achieved by insertion of either a Fogarty embolectomy catheter or commercially available endobronchial blocker into the mainstem bronchus of the involved lung. The balloon is then inflated until occlusion of the bronchus occurs and lung separation is achieved. While protective of the normal lung, such blockade of the pathological side increases Qs/Qt and can cause worsening hypoxemia despite compensatory hypoxic pulmonary vasoconstriction. Lateral decubitus positioning, to gravitationally divert pulmonary blood flow to aerated lung segments, and application of differential PEEP to recruit alveoli in the normal lung can ameliorate these effects.

Physiological separation is required when asymmetric lung disease, such as unilateral parenchymal injury or bronchospasm, BPF, or single lung transplant necessitates implementation of different ventilator strategies for each lung in order to maintain adequate oxygenation and ventilation. A DLT is the method of choice for achieving physiological lung separation. Proper placement and positioning of the DLT is essential to the success of ILV and should be deferred to a physician with experience in the use of this device. An excellent review of this subject including an algorithm for confirming appropriate placement has been written by Ost & Corbridge (3). Even small movements of the tube, as may occur during routine patient care, may compromise lung separation and ILV. Sedation and neuromuscular paralysis are commonly necessary. If DLT displacement is suspected, tube position should immediately be confirmed via bronchoscopy with repositioning as necessary. The small lumens of a DLT can make bronchial hygiene and suctioning as well as bronchoscopy difficult (4). The most common complications associated with the use of a DLT include laryngeal trauma, bronchial trauma, and obstruction of the DLT lumens. The volume of air necessary to seal the cuffs of a DLT is relatively small; inflation with larger volumes can lead to mucosal injury and even bronchial rupture. The small lumens of a DLT can make bronchial hygiene and suctioning as well as bronchoscopy difficult if not impossible (4).

Application of Ventilatory Support

Ventilatory support in ILV can be performed either synchronously or asynchronously with equivalent safety and outcome (1,3,5). In synchronous ILV, the respiratory rate applied to each lung is the same, but the tidal volume, inspiratory flow, PEEP, and FiO_2 are selectively titrated to optimize oxygenation and ventilation while minimizing the potential for VILI in each lung. As most commonly performed, synchronous ILV requires two mechanical ventilators with special software that are synchronized using an external cable. In asynchronous ILV, the respiratory rate, tidal volume, inspiratory flow, PEEP, FiO_2, and even mode of support (controlled mechanical ventilation, intermittent mandatory ventilation, pressure control ventilation, high frequency oscillatory ventilation, continuous positive airway pressure, etc…) can differ from one lung to the other. Asynchronous ILV does not require specialized software packages and is considered to be less complicated than synchronous ILV (1,3,5).

Initial ventilatory support in ILV should be selected based upon the individual patient's pulmonary pathophysiology. A reasonable starting point would be an initial tidal volume of 5 mL/kg in the normal lung and 2 mL/kg in the injured lung, titrated to achieve adequate ventilation while maintaining plateau airway pressures below 26 cm H_2O, which has been demonstrated to optimize PaO_2/FiO_2 and compliance (6,8). Respiratory rate, inspiratory flow, PEEP, and FiO_2 should be adjusted to optimize oxygenation and carbon dioxide excretion while, in the patient with a BPF, simultaneously minimizing air leak. ILV should be continued as long as is necessary to allow sufficient healing of the injured lung such that the tidal volume and compliance of the two lungs differs by less than 100 mL and 20% respectively (8). At that time, conventional mechanical ventilation using a single-lumen endotracheal tube can generally be reinstated and the patient weaned as tolerated.

The Effect of Patient Positioning During Independent or Single Lung Ventilation

Patient positioning may be important when single or one lung ventilation has been initiated. Gravity has been shown to be an important determinant of oxygenation while utilizing single lung ventilation. Placing the ventilated lung down in the lateral decubitus position has been shown to improve arterial PaO2 (9,10).

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