Whole-Lung Lavage

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Introduction

Whole-lung lavage (WLL) is a large-volume bronchoalveolar lavage performed primarily for the treatment of pulmonary alveolar proteinosis (PAP). Pulmonary alveolar proteinosis is a primary or an acquired form of macrophage dysfunction that results in abnormal processing of surfactant. Over the course of time, amorphous, acellular phospholipids and surfactant apoproteins accumulate and fill the alveoli leading to impaired gas exchange. This causes a subacute onset of exertional dyspnea which progresses over the course of time. Physical removal of the accumulating amorphous material from the alveoli by a WLL is the most widely accepted and effective therapy for PAP. The procedure involves intubating a patient with a double-lumen endotracheal tube, ventilating a single lung while performing a large-volume (up to 20 L) lavage of the nonventilated lung with the goal of clearing the abnormal proteinaceous material from the alveoli. The details of the procedure are discussed below.

History

The abnormal accumulation of amorphous material in the alveoli of patients affected with PAP was first described in 1958. Initial attempts at treating PAP included systemic antibiotics and corticosteroids and dissolution of the proteinaceous material in the lungs with streptokinase, trypsin, heparin, and acetylcysteine, all without much success. In 1960, Jose Ramirez-Rivera first described the process of physically removing the proteinaceous material by "segmental flooding" of the alveoli. The procedure involved

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placing a percutaneous transtracheal endobronchial catheter blindly and instilling a small volume (50–100 ml) of saline solution containing heparin, acetylcysteine, or sodium iodide. This triggered a cough, and the patients expectorated a small quantity of milky-white fluid. This was performed four times a day for several weeks while changing the patient's physical position to direct the instilled fluid into different segments. Segmental lavage was shown to improve symptoms, but the procedure was time consuming and was poorly tolerated by the patients. Dr. Ramirez-Rivera continued to improvise on the procedure and, in 1965, introduced "whole-lung lavage." The technique involved intubating the patient with a double-lumen Carlens bronchospirometry tube under general anesthesia, ventilating a single lung while filling the other lung with normal saline containing heparin or acetylcysteine. A total of 1.3–1.8 L of fluid was used to fill the lung over 10 min; patient was then allowed to ventilate normally. Part of the lavage fluid was then drained by gravity, which was followed by vigorous ventilation of the lung. Suctioning was then performed to drain out the milky-white effluent, and the patient was recovered from anesthesia. Following the initial description of the technique, multiple case reports and case series established the safety of the procedure, and sequential whole-lung lavage became the standard treatment in patients with PAP. Over the last five decades, the technique has undergone a few changes; WLL now involves larger fluid volumes, use of normal saline alone without heparin or acetylcysteine, and the routine use of chest percussion during the procedure.

Indications for Whole-Lung Lavage

In early publications in the 1960s, WLL was performed in patients with PAP, chronic asthmatic bronchitis with mucus plugs, and unresolved bacterial pneumonias. Current literature supports the use of WLL in the following conditions:

1. Pulmonary alveolar proteinosis

   Pulmonary alveolar proteinosis is a rare disease characterized by accumulation of surfactant components in the
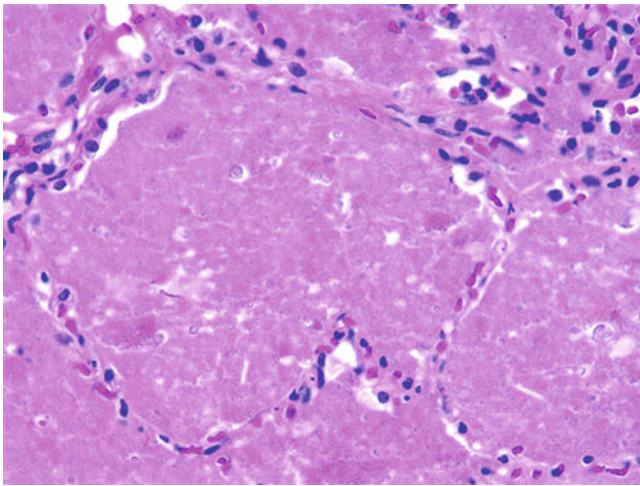
Fig. 71.1 Histology of PAP. Well-preserved alveoli with the accumulation of amorphous lipoproteinaceous material that stains *pink* with periodic acid-Schiff stain and a distinct absence of inflammatory cells

Fig. 71.2 CT scan image of PAP. Patchy areas of ground glass with thickening of the interlobular septa creating a "*crazy-paving*" pattern

alveoli with minimal to no inflammation. If left untreated, PAP results in impaired gas exchange, progressing in some cases to respiratory failure. Congenital, acquired, or secondary causes can to lead to PAP. The acquired form of PAP is more common and is seen in adults, where a circulating antibody to granulocyte-macrophage colony-stimulating factor (GM-CSF) causes a reduction in GM-CSF activity in the lung. This leads to impairment in degradation of surfactant by the alveolar macrophages, which are dependent on GM-CSF. In the congenital form of PAP, genetic mutations result in abnormal surfactant proteins or defective GM-CSF receptors. Secondary PAP is seen in patients with lysinuric protein intolerance, acute inhalational exposures (silica, cement dust, aluminum dust, or titanium dioxide), immunodeficiency disorders, and myeloid leukemias. Irrespective of the etiology, the common endpoint is the accumulation of PAS-positive acellular material in the alveoli (Fig. 71.1) that causes the characteristic "crazy-paving" pattern of ground-glass opacities and septal thickening seen on chest computed tomography scans (Fig. 71.2). In PAP, WLL is indicated when the patients progress to severe dyspnea and hypoxia at rest or with activity, resting PaO_2 less than 65 mmHg at sea level, A-a gradient greater than or equal to 40 mmHg, or measured shunt fraction greater than 10–12 %.

2. Inhalational lung toxicities

   Case reports have suggested WLL as a therapeutic option in inhalational lung injuries, predominantly occupational lung disorders with diffuse pulmonary damage. In these situations, WLL is aimed at removing the mineral dust that cannot be otherwise eliminated by the body. Whole-lung lavage has been performed in patients with exogenous lipoid pneumonia, acute silicosis, lung injury from inhaled plutonium oxide, and pneumoconiosis. Long-term benefits of WLL in these situations are unknown.

Effects of WLL

Beneficial effects of WLL are well established in case series of patients with PAP. Although no criteria to measure adequacy of response are established, 84 % of the patients have a significant clinical, physiologic, and radiologic improvement following WLL. Patients who undergo WLL at any time during the course of their disease have a survival benefit when compared to those who do not undergo the procedure (Fig. 71.3). Studies that compare pulmonary parameters (PaO_2, A-a gradient, DL_{co}, vital capacity, pulmonary shunt fraction) before and after performing WLL have shown a significant improvement with the procedure. The median duration of benefit following WLL is 15 months, and approximately two-thirds of the patients will require a repeat lavage, usually within 6–12 months.

Procedural Considerations

1. Equipment

   Lavage is performed with 15–20 L of sterile normal saline, and the fluid is run through a blood warmer to maintain adequate core body temperature. We also
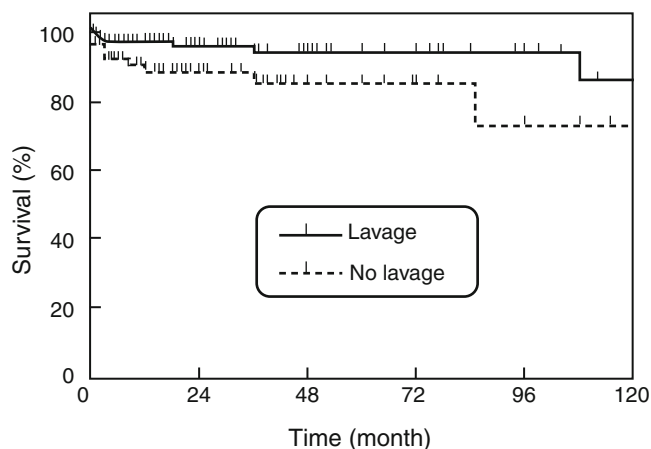
Fig. 71.3 Overall survival from the time of diagnosis of acquired PAP was significantly improved if patients had received therapeutic lavage at any time during their disease course (lavage, n=146; no lavage, n=85; p=0.044) (Reprinted with permission of the American Thoracic Society. Copyright © American Thoracic Society. Seymour JF, Presneill JJ. Pulmonary alveolar proteinosis progress in the first 44 years. Am J Respir Crit Care Med. 2002;166:215–35. Official Journal of the American Thoracic Society)

Fig. 71.4 Whole-lung lavage equipment and setup. The lavage fluid is hung in multiliter bags from an IV pole and run through a warmer. A lock is located between the lavage fluid and warmer to control the volumes and timing of the lavage fluid being instilled. The dependent lung is ventilated, while the other is being lavaged. The lavage and drainage limbs are in continuity with the lavage lung only. There is a lock in the drainage limb to control the timing of drainage into the fluid collector

recommend a warming blanket (Bair Hugger; Arizant, Inc., Eden Prairie, MN) covering the exposed body surface to prevent hypothermia, given the prolonged duration of the procedure. Tubing that is generally used for intravenous fluids is connected via an adapter to the double-lumen endotracheal tube to form the inflow and the outflow limbs. Flow through the tubing is controlled with stopcocks. A thin bronchoscope that can be used through the double-lumen endotracheal tube to verify tube position or aspirate secretions should be available at patient's side. Multiple drainage receptacles are needed to collect the effluent. Anesthesia team that is comfortable with intubation with a double-lumen endotracheal tube and single-lung ventilation is required for the procedure.

2. Procedure

General anesthesia is recommended for the procedure. The patient is initially placed on their back on the operating table and intubated with a double-lumen endotracheal tube. Flexible bronchoscope is used to confirm the tube placement. The bronchial and the tracheal balloons are inflated to isolate the lungs, and double-lung mechanical ventilation is initiated. The patient is then turned to a lateral decubitus position, with the lung being lavaged up in the nondependent position. Meticulous care should be taken to avoid ischemic complications to the extremities by placing supporting pillows in the axilla, under the head, and between the thighs. The position of the endotracheal tube should be reconfirmed. Lung isolation is confirmed by immersing the end of each lumen of endotracheal tube in water and observing for air bubbles while
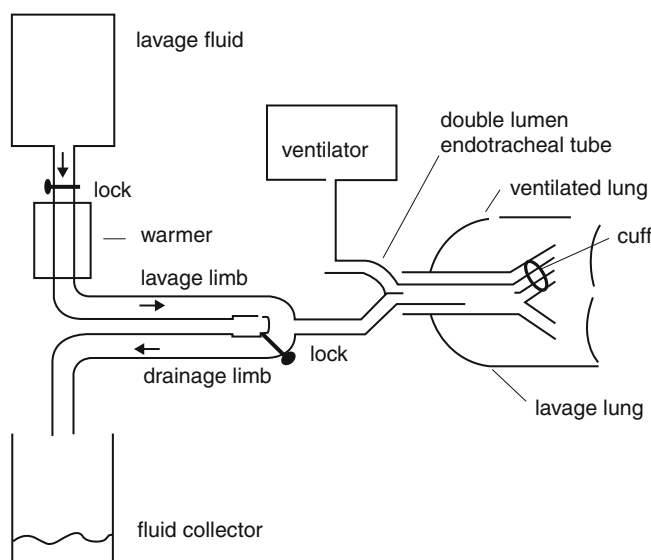
ventilating the other lung. Single-lung ventilation is then initiated, and the tube to the lung to be lavaged is opened to the atmosphere and allowed to deflate. The limb of the double-lumen endotracheal tube that is open to the lung to be lavaged is then connected to the normal saline reservoir (Fig. 71.4). Prior to filling the lung with the fluid, sufficient time should be given to confirm adequate oxygenation while ventilating a single lung.

With the patient in reverse Trendelenburg position (head end slightly elevated), warm (37 °C) normal saline is allowed to flow freely into the treated lung through the endotracheal tube limb. After allowing 1 L of fluid to run, the tubing is clamped. The patient is tilted into a flat position, and percussion of the lung is performed for approximately 4–5 min. The patient is then tilted into a Trendelenburg position (feet elevated), and the clamp on the outflow tube is released to drain the effluent by gravity into a receptacle. When the flow diminishes, the outflow tube is clamped, the patient is placed in reverse Trendelenburg position, and another liter or warm normal saline is allowed to flow into the lung, and the process is repeated. The initial effluent is milky in appearance that tends to settle on standing. After 10–15 lavages, the fluid becomes progressively less opaque, and when it is clear, the procedure is terminated. Residual saline in the lung is aspirated, and double-lung ventilation is resumed. The input and output of the lavage fluid is carefully charted to prevent excessive residual fluid in the lung. A video

featuring the procedure is available for viewing at http:// chestjournal.chestpubs.org/site/misc/videos/media1/ index.html.

3. Postprocedure

The patient is repositioned onto the back and if stable, extubated in the operating room. Otherwise, the double-lumen endotracheal tube is exchanged for a single-lumen tube, and the patient is transferred to the recovery area. Patients can be safely extubated within 24 h, in most cases. In patients with bilateral disease, we prefer to lavage the contralateral lung in 24–48 h, although bilateral sequential whole-lung lavage in the same treatment session can be performed in stable patients.

A chest radiograph is performed after the procedure to evaluate for complications such as pleural effusion or a pneumothorax. A pleural drain may be necessary, especially if treatment of the contralateral lung is planned, to prevent intraprocedural decompensation of the patient.

4. Complications

Whole-lung lavage is tolerated well in most patients. The common complication is intraoperative refractory hypoxia which tends to be more of an issue during the lavage of the first lung. Low oxygen saturation (70–80 % range) is not uncommon, especially at the onset of the procedure. This tends to improve spontaneously without any additional interventions. Care should be taken to avoid spillage of lavage fluid into the dependent lung that is being ventilated, which can contribute to hypoxia. If necessary, the positioning of the double-lumen endotracheal tube should be reconfirmed with a bronchoscope, and any visible lavage fluid in the lung being ventilated should be suctioned clean. If required by the severity of hypoxia, hyperbaric oxygen, cardiopulmonary bypass, and extracorporeal membrane oxygenation may be utilized.

Other complications include pleural effusion, pneumothorax, or hydropneumothorax on the treated side. These can be avoided with meticulous charting of the infused saline and the output and by taking care not to allow instilled fluid to exceed the fluid drained by more than a few hundred milliliters in consecutive lavages.

Conclusion

Whole-lung lavage is a safe and an effective procedure in the treatment of PAP. Although research is underway to develop alternatives such as GM-CSF administration in patients with acquired PAP, WLL remains the cornerstone of management in symptomatic patients with all forms of PAP. Most patients with PAP will eventually require WLL, and a majority of them will need a repeat procedure during the course of the illness.

Complications from the procedure are minimal, especially when performed in centers with adequate resources and experience with single-lung ventilation.

Suggested Reading

1. Michaud G, Reddy C, Ernst A. Whole lung lavage for pulmonary alveolar proteinosis. Chest. 2009;136:1678–81.
2. Ramirez JR, Kieffer RF, Ball WC. Bronchopulmonary lavage in man. Ann Intern Med. 1965;63:819–28.
3. Seymour JF, Presneill JJ. Pulmonary alveolar proteinosis progress in the first 44 years. Am J Respir Crit Care Med. 2002;166:215–35.
4. Beccaria M, Luisetti M, Rodi G, et al. Long-term durable benefit after whole lung lavage in pulmonary alveolar proteinosis. Eur Respir J. 2004;23:526.
5. Hammon WE, McCaffree DR, Cucchiara AJ. A comparison of manual to mechanical chest percussion for clearance of alveolar material in patients with pulmonary alveolar proteinosis (phospholipidosis). Chest. 1993;103:1409.
6. Ramirez J. Pulmonary alveolar proteinosis: treatment by massive bronchopulmonary lavage. Arch Intern Med. 1967;119:147–56.
7. Rogers RM, Levin DC, Gray BA, et al. Physiologic effects of bronchopulmonary lavage in alveolar proteinosis. Am Rev Respir Dis. 1978;118:255–64.
8. Rogers RM, Szidon JP, Shelburne J, et al. Hemodynamic response of the pulmonary circulation to bronchopulmonary lavage in man. N Engl J Med. 1972;286:1230–3.
9. Ben-Abraham R, Greenfeld A, Rozenman J, et al. Pulmonary alveolar proteinosis: step-by-step perioperative care of whole lung lavage procedure. Heart Lung. 2002;31:43–9.
10. Sivitanidis E, Tosson R, Wiebalck A, et al. Combination of extracorporeal membrane oxygenation (ECMO) and pulmonary lavage in a patient with pulmonary alveolar proteinosis. Eur J Cardiothorac Surg. 1999;15:370–2.