Bronchopulmonary Lavage
New Techniques and Observations*

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In a recent article, a method of bronchopulmonary lavage was presented based on actively inhaling and exhaling fluid with one lung while breathing 100 per cent oxygen with the other.1 Experience with these first 12 lavages showed that bronchi and alveoli of man could be safely debrided by this technique. Unfortunately, the effectiveness of the method was seriously hampered by the fact that the mechanics of washing were provided by the patient's respiratory efforts and that the same fluid was used for the ten minute washing period. At the suggestion of Kylstra,2 who has had extensive experience with pulmonary lavage in dogs, the technique has been modified so that the filling and emptying of the lung no longer requires the assistance of the patient. Consequently, lavages may now be performed for longer periods and with larger volumes of solution. The technique as currently applied, and pertinent clinical and laboratory observations during 25 lavages in seven patients form the basis of this report.

Materials and Methods
Twenty lavages were performed on five patients with alveolar proteinosis; three on a patient seen in status asthmaticus on three separate occasions; and two on a patient with chronic bronchitis, but without severe respiratory impairment.

The patients with alveolar proteinosis were lavaged with a 0.9 per cent saline solution containing 5.0 to 7.5 units of heparin per ml., a solution containing 1 per cent acetylcysteine, or a solution containing both acetylcysteine and heparin. The patients with bronchitis and asthma were lavaged with a saline solution containing 1 per cent acetylcysteine. All solutions were buffered to pH 8.6 by adding 75 ml. of bicarbonate buffer to each liter of solution. This buffer was prepared by mixing 0.1 molar NaCO3 with 0.1 molar NaHCO3 in ratio of 5:95. The resulting solution was hypertonic with an osmolality of approximately 520 milliosmols per liter.

The simple equipment used for the lavage is demonstrated in Figure 1. The volume of the pulmonary washings and of the sediment which precipitated from them in two hours were carefully measured. Samples of the sediment were fixed in formalin and in alcohol. Histologic preparations of the sediment were stained with Alcian green and PAS media and examined microscopically.4 Respiratory function was studied in all patients before and after the lavage.

Technique of Pulmonary Lavage
After topical anesthesia to pharynx and trachea, or after light general anesthesia, the ventilation to each lung was separated with a Carlens bronchospimetry tube.5 Most of the alveolar nitrogen was removed by ventilating both lungs with 100 per cent oxygen for ten minutes and, subsequently, the lung selected for lavage was partially degassed by totally obstructing its ventilation for five minutes. The degassed lung was then filled rapidly with irrigating solution with a filling pressure not exceeding 30 cm. of saline (Fig. 1A). After complete filling, the fluid and sediment was rapidly drained into a conventional type water-sealed bottle placed 60 cm. below the level of the mid-chest (Fig. 1B). The lung was then filled and emptied three times.

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to ten times. During the lavage, the ventilated lung was frequently checked by auscultation to detect any leakage of fluid; pulse rate and blood pressure were carefully monitored in order to be aware of changes in cardiac output.

After the last filling, the patient was placed in the Trendelenburg position to encourage drainage, and a suction apparatus was connected to the drainage bottle. The lung was then ventilated (Fig. 1B clamp "A" opened), and gently evacuated by suction (Fig. 1B - clamp "B" opened and clamp "A" intermittently closed) three or four times. Suctioning pressure was maintained at less than 10 cm. of mercury to prevent bronchiolar collapse. After the lavage, oxygen was administered with an intermittent positive pressure device for 20 to 30 minutes. Thereafter, oxygen was administered by nasal cannula only if necessary. Within two hours, most patients were ambulant.

| Table 1—Respiratory Functions Studies on Patients with Alveolar Proteinosis. |
|-------------------|---------------------------|-------------------|-------------------|-------------------|-------------------|
|                   | Predicted | Before Lavage 3/1/65 | 2 weeks after 2nd Lav. 3/19/65 | 5 days after 5th Lav. 3/31/65 | 7 weeks after 8th Lav. 6/21/65 |
| Vital capacity (L) | 4.8 | 1.2 | 1.9 | 2.4 | 2.5 |
| One sec. timed vital capacity (%) of total | 80 | 70 | 63 | 79 | 78 |
| Total lung volume (L) | 6.3 | 1.6 | 3.4 | 4.5 |
| Arterial Oxygen saturation (%) Rest | 96-98 | 53 | 81 | 91 | 96 |
| Arterial CO₂ tension (mm. Hg) Rest | 35-46 | 35 | 29.1 | 30 | 43 |
| Venous admixture (%) Rest | 6 | >50 | >50 | 37 | 13 |
| Diffusing capacity for CO ml/min/mm. Hg | 19.2 | 2.1 | 3.9 | 4.0 | 9.5 |
Figure 2: Roentgenograms of patient with alveolar proteinosis. (A) Before pulmonary lavage. (B) Two weeks later after two pulmonary lavages showing further clearing. (C) Four weeks after A and after an additional three lavages showing further clearing.
Observations

In general, it was thought preferable to lavage the lung using topical anesthesia, and 17 of the 25 lavages were performed in this manner. Light general anesthesia was administered to the very apprehensive patients, and was required for long procedures, when more than 6 liters of irrigating fluid were used. Patients, routinely premedicated with morphine, pentobarbital sodium (Nembutal) and atropine, were vaguely aware of the filling and emptying of the lung; cough occurred only towards the end of the emptying phase and when the lung was repeatedly evacuated by suction. The actual washing was a simple and rapid process. Filling the lung with 1500 ml. of irrigating solution took approximately three minutes and emptying it, two minutes. After placing the bronchospirometry tube, lavages of 5 or 6 liters of fluid required approximately 30 minutes. Four lavages with 10 to 12.5 liters of fluid were completed in less than one hour.

No attempt was made to evacuate the fluid completely at the end of the procedure, although, as a rule, more than 90 per cent of the irrigating fluid was recovered. The roentgenogram two and six hours after the lavage showed that the repeated ventilation and partial evacuation of the irrigated lung hastened the reabsorption of the remaining fluid. In most instances, only fine basilar rales could be heard over the treated lung two hours after the lavage. Once the practice of suction-evacuation was initiated, the transient hypoxemia generally observed during the first hours after the completion of the lavage was less marked and easily corrected by the administration of oxygen.

The five patients with alveolar proteinosis and the patient with chronic bronchitis tolerated the procedure well. Three patients with alveolar proteinosis of recent onset and with extensive involvement showed rapid resolution of the pulmonary infiltrates and a substantial improvement in respiratory function within two weeks after the lavage. In the other two patients who had been treated with partial success by repeated segmental irrigations (Cases 3 and 4), gradual roentgenographic and physiologic improvement was measurable over a 12 month period.

The effectiveness of bronchopulmonary lavage in the treatment of alveolar proteinosis was best exemplified by a 30-year-old man with severe pulmonary insufficiency, cor pulmonale and secondary polycythemia. The pulmonary infiltrates were bilateral and extensive (Figure 2A). Even though receiving oxygen constantly, he was hypoxic at rest because more than 50 per cent of the cardiac output was perfusing an unventilated capillary bed (Table 1). Segmental pulmonary irrigation had been tried repeatedly elsewhere over a period of three months, but it had failed because of inadequate ventilatory capacity to expell the viscous broncho-alveolar contents. Because of the severe respiratory failure, the functional capacity of the individual lungs was studied by bronchospirometry two weeks preceding the lavage. Both lungs appeared to be equally involved, but it was demonstrated that the ventilation of one lung could be totally occluded for ten minutes while the other lung was ventilated with 100 per cent oxygen. With this fact established, the left lung was hastily filled and emptied three times within ten minutes. Forty-eight hours later, the right lung was irrigated without taking any unusual precautions. Significant clearing of the pulmonary infiltrates was readily apparent two weeks after the first two lavages (Fig. 2B); and after three additional lavages, further clearing occurred (Fig. 2C). From 18,620 ml. of pulmonary washing obtained, a total of 6,215 ml. of proteinaceous material precipitated (Fig. 3A). Respiratory function improved dramatically (Table 1). Three months after therapy was initiated, the patient was able to return to work. Right pulmonary biopsy one month after lavaging the right lung for the fourth time showed, in a few isolated areas, changes compatible with alveolar proteinosis, but for the most part
BRONCHOPULMONARY LAVAGE

the lung appeared normal by light and electron microscopy. The patient with chronic bronchitis was lavaged twice with 6 liters of saline solution containing 1 per cent acetylcysteine. Less than 30 ml. of sediment precipitated

Figure 3: Morphologic comparison of pulmonary sediments. (A) Acellular in alveolar proteinosis. (B) Cellular in chronic bronchitis.

Figure 4: Harvest of bronchial casts in bronchopulmonary washings of patient in status asthmaticus.
<table>
<thead>
<tr>
<th>Time A.M.</th>
<th>Conditions</th>
<th>Clinical Observations</th>
<th>Pulse</th>
<th>Blood Pressure</th>
<th>pO₂</th>
<th>pCO₂</th>
<th>pH</th>
<th>O₂ Saturation (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:55</td>
<td>Bronchospirometry tube in place, breathing air</td>
<td>Moderately cyanotic Severe wheezing</td>
<td>120</td>
<td></td>
<td>38</td>
<td>73</td>
<td>7.24</td>
<td>62</td>
</tr>
<tr>
<td>9:04</td>
<td>Breathing 100% O₂ (3 min.)</td>
<td>Pink, restless</td>
<td>100</td>
<td>180/120</td>
<td>110</td>
<td>89</td>
<td>7.15</td>
<td>99</td>
</tr>
<tr>
<td>9:07</td>
<td>Lavage initiated</td>
<td>Asleep (?)</td>
<td>100</td>
<td>180/130</td>
<td>98</td>
<td>125</td>
<td>7.07</td>
<td>96</td>
</tr>
<tr>
<td>9:11</td>
<td>Lavage terminated</td>
<td>Unconscious</td>
<td>100</td>
<td></td>
<td>116</td>
<td>140</td>
<td>7.03</td>
<td>94</td>
</tr>
<tr>
<td>9:20</td>
<td>Repeated suctioning Hyperventilation with 100% O₂ (5 min.)</td>
<td>Unconscious</td>
<td></td>
<td></td>
<td>113</td>
<td>130</td>
<td>7.06</td>
<td>96</td>
</tr>
<tr>
<td>9:31</td>
<td>Repeated suctioning Hyperventilation with O₂ continued (16 min.)</td>
<td>Awake and restless</td>
<td>110</td>
<td>150/100</td>
<td>85</td>
<td>92</td>
<td>7.18</td>
<td>93</td>
</tr>
<tr>
<td>10:30</td>
<td>On IPPB with 40% O₂ for 10 minutes</td>
<td>Feels he can breathe better</td>
<td>110</td>
<td>140/90</td>
<td>151</td>
<td>66</td>
<td>7.38</td>
<td>88</td>
</tr>
<tr>
<td>11:00</td>
<td>Breathing room air</td>
<td>Fewer rales and rhonchi over lavaged lung</td>
<td></td>
<td></td>
<td>58</td>
<td>54</td>
<td>7.38</td>
<td>88</td>
</tr>
</tbody>
</table>

P.M. 1:50 Breathing room air Ambulant |       |        | 76   | 54   | 7.36| 93   |
in two hours from the washings of each lung. The sediment was extremely cellular and contained little identifiable mucous. The cells were predominantly macrophages and many were distended with vacuoles of lipoid material (Fig. 3B). The appearance of the sediment differed greatly from that of the patients with alveolar proteinosis.

Although the bronchial secretions of the patient with bronchitis were markedly thinner for 48 hours after the lavage, no reduction in sputum volume, or permanent change in its viscosity was caused by the procedure. The vital capacity, total lung capacity, and diffusing capacity were unchanged eight weeks later. This observation suggests that bronchopulmonary lavage may do little to change the clinical course of chronic bronchitis.

The two main complications observed in the first 12 lavages were again noted: one patient had significant spilling into the contralateral lung, and another patient had transient atelectasis of the left upper lobe after the lavage. In this group of patients, two additional complications were observed. The systolic blood pressure in one of the patients with alveolar proteinosis, who also had pulmonary fibrosis, dropped to a level of 56 to 65 mm Hg each time the lung was filled with fluid. Carbon dioxide narcosis was produced three times on a young, aggressive patient seen on three separate occasions in status asthmaticus.

The asthmatic patient felt so improved after the first lavage that he readily accepted repetition of the procedure. The detailed observations during and after a S0 ml. lavage are presented in Table 2, and the bronchial casts in the sediment of the pulmonary washings are shown in Fig. 4. Hypercarbia occurred while breathing 100 per cent oxygen even though oxygen breathing was limited to five minutes. Carbon dioxide narcosis rapidly developed when the ventilation of one lung was totally obstructed. Although the risk of CO₂ narcosis clearly prohibits the use of bronchopulmonary lavage on patients in severe status astmaticus, the doubling of the oxygen tension in the arterial blood and the decreasing carbon dioxide tension five hours later suggests that the procedure had a beneficial effect. It would appear, therefore, that the effect of bronchopulmonary lavage on chronic bronchial asthma merits further study.

**Comment**

Tracheobronchial lavage may be performed through cuffed endobronchial or tracheostomy tubes. Individual pulmonary segments may also be lavaged through a bronchoscope using tightly-fitting catheters to inject and aspirate irrigating solutions or, in patients who can cough effectively, through a semi-permanent endobronchial catheter introduced percutaneously through the cervical trachea. Although the larger airways may be effectively irrigated with these methods, the distal airspaces are reached in a limited and uncertain way.

This limited effectiveness of bronchial irrigations when compared to bronchopulmonary lavage is readily illustrated by the clinical course of the patient with severe alveolar proteinosis briefly presented here. In this patient, five weeks of treatment with daily endobronchial irrigations within a period of three months failed to bring about clinical or roentgenographic improvement. In contrast, when bronchopulmonary irrigation was initiated, large amounts of alveolar material were removed, the chest roentgenograms cleared, and the respiratory function improved.

The classic studies of Winternitz and Smith in 1920, and recent observations, demonstrate that the lung may be filled to capacity with physiologic solutions without causing damage to the pulmonary parenchyma. The lack of tissue change in a biopsy performed one month after four pulmonary lavages in the patient with severe alveolar proteinosis presented here further confirms these observations.

Adequate respiratory function must be demonstrated before undertaking bronchopulmonary lavage. Patients to be treated...
by this method must have enough functional capacity in the ventilating lung to eliminate their entire output of carbon dioxide, and enough capillary bed in that lung to accommodate the entire cardiac output.

The effectiveness of bronchopulmonary lavage in the treatment of alveolar proteinosis has been clearly demonstrated, but other clinical uses have not been sufficiently explored. The technique of lavage presented here should make these exporations easier and safer.

SUMMARY
A technique for bronchopulmonary lavage is presented as currently applied in the treatment of alveolar proteinosis and other bronchopulmonary disorders. This is a modification of a method previously published. It permits repeated irrigation of a whole lung with liters of a saline solution containing acetylcysteine or heparin while the other lung is ventilated with 100 per cent oxygen. Clinical and laboratory observations during 25 lavages in seven patients are summarized. Bronchopulmonary lavage is effective in the treatment of alveolar proteinosis, may be helpful in the treatment of bronchial asthma, but does not appear useful in the treatment of chronic bronchitis. The technique presented should make bronchopulmonary lavage easier and safer.

ACKNOWLEDGMENT:
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RESUMEN
El autor presenta una técnica para el lavaje pulmonar, tal como se aplica corrientemente en el tratamiento de la proteinosis alveolar y otras afecciones bronco-pulmonares. Esta técnica consiste en una modificación de un método publicado con anterioridad y permite la irrigación del pulmón entero, con varios litros de solución salina conteniendo acetyl-cisteína o heparina, mientras el otro pulmón está siendo ventilado con oxígeno puro. Se relatan las observaciones clínicas y de laboratorio en el curso de 25 lavajes en siete pacientes.

El lavaje broncopulmonar es de eficacia probada en el tratamiento de la proteinosis alveolar y puede ser efectivo en el del asma bronquial, pero no parece útil en la bronquitis crónica. En la experiencia del autor esta técnica hace del lavaje pulmonar un procedimiento fácil y seguro.

REFERENCES

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