Bronchopulmonary Lavage in Asthma and Chronic Bronchitis: Clinical and Physiologic Observations*

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Two patients with bronchial asthma and five patients with chronic bronchitis were subjected to a reproducible method of pulmonary lavage. Physiologic events were studied during the procedure, immediately afterwards, and at periodic intervals. During the lavage, arterial oxygen tensions varied between 56 and 570 mm Hg and oxygen saturations exceeded 90 percent. Partially obstructed areas were successfully irrigated by filling and emptying of the lung repeatedly. Cardiac output, pulmonary and systemic arterial blood pressures were affected very slightly. Transient respiratory acidosis and fever occurred after four procedures. Postlavage hypoxemia and hypercarbia were effectively controlled with respiratory assistance and oxygen. Five patients improved subjectively and physiologic improvement was documented in two. Signs of improvement had disappeared by seven months in all but one patient. Bronchopulmonary lavage may be effectively and safely performed in patients who have moderately severe asthma or bronchitis. The therapeutic benefit of this procedure merits further study.

Although the therapeutic merit of bronchopulmonary lavage has been documented in the treatment of alveolar proteinosis,¹,² its usefulness and safety has not been established in the treatment of chronic bronchitis or asthma. Birley and Rochford³ reported 28 successful unilateral lavages in asthmatic patients using small volume of saline. Kylstra and associates,⁴,⁵ using larger volumes of saline, noted clinical and physiologic improvement in two asthmatic patients immediately after the lavage, and recently similar observations were reported in 18 other patients with asthma and bronchitis. Variations in methodology and in the selection of clinical material have made these results difficult to assess. Further study of the clinical practicability of this technique depends on the application of a safe and reproducible method, careful definition and long-term physiologic study of patient material, and a deeper acquaintance with physiologic events during the procedure. Detailed physiologic and hemodynamic studies during lavage have been reported in a single patient with alveolar proteinosis.⁶

The present study describes a reproducible method for pulmonary lavage. Lavage was performed in patients with potentially reversible obstructive airway disease after intensive conservative treatment. Measurements and observations of respiratory and hemodynamic events during and after lavage demonstrate that the procedure is safe, will acutely open airways, but may have limited long-term effectiveness.

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Application of Methods
Selection of Patients and Preparation

Seven men patients between 42 and 53 years of age with asthma or bronchitis were studied during a total of 15 lavages. Their diagnoses were made according to the Committee on Therapy of the American Thoracic Society.⁷ Al-
though moderate airway obstruction and some degree of arterial hypoxemia were present in all patients, none was hypercapnic (Table 1).

All subjects were treated with 1 to 12 weeks of intensive bronchial toilet, including postural drainage, bronchodilator, expectorants and antibiotic therapy prior to lavage. Lavage was performed after maximal clinical and laboratory improvement had been reached as judged by no further decrease in sputum production or change in respiratory function for at least one week. Preoperative medications consisted of 50 to 100 mg secobarbital and 0.6 mg atropine sulfate administered parenterally. No narcotics were used in order to prevent alveolar hypoventilation.

Lavage Procedure

The basic technique of pulmonary lavage has been previously reported.1 For this study several important modifications were made. General anesthesia was always used. Anesthesia was induced with a gas mixture of 2 percent to 3 percent halothane (Fluothane) and 97 to 98 percent oxygen mixture and lightly maintained with a 0.5 percent halothane (Fluothane) 99 percent oxygen mixture. Succinylcholine was used initially to facilitate prompt placement of a Carlens catheter. It was used repeatedly during the lavage to suppress cough. Arterial oxygen and carbon dioxide tensions (Pao2 and Paco2) and pH were measured serially from samples obtained through an indwelling arterial cannula placed before intubation. Samples were taken during each step of the procedure and one, two, five and six hours after intubation. In addition, systemic arterial and pulmonary artery pressures and cardiac outputs, by the cardiogreen dye dilution technique, were measured and recorded on an Electronics for Medicine multichannel recorder* during five lavages in five patients (Fig 2). Serial samples of mixed venous and systemic arterial blood were withdrawn simultaneously connected to the ventilator and the tidal volume increased 200 to 500 ml. As the fluid welled out from the lavaged airway with ventilation, it was repeatedly and quickly suctioned. There was no attempt to suction the bronchi before extubation. During each lavage, aminophylline (0.5 mg/ml) was infused intravenously at varying rates to decrease bronchospasm. Because most patients had received corticosteroids in preceding weeks, 100 mg hydrocortisone sodium succinate was usually administered.

Electrocardiograms were continuously monitored during each lavage. In addition, systemic arterial and pulmonary artery pressures and cardiac outputs, by the cardiogreen dye dilution technique, were measured and recorded on an Electronics for Medicine multichannel recorder* during five lavages in five patients (Fig 2). Serial samples of mixed venous and systemic arterial blood were withdrawn simultaneously.

*Electronics for Medicine, Inc.
for calculation of the percent venous admixture by using the shunt equation. For these measurements a pulmonary artery catheter was inserted percutaneously through a peripheral vein.

Postlavage Procedure and Other Studies

After the subjects regained consciousness, the Carlens tube was removed and ventilation was assisted by intermittent positive pressure breathing (IPPB) with 40 percent to 80 percent oxygen for 30 to 60 minutes. Thereafter, the PAO₂ was maintained at levels of 50 to 70 mm Hg with a 28 percent Ventimask or with nasal oxygen (2 to 8 liters per minute) and the IPPB used for 10 to 15 minutes every hour. Patients were encouraged to assume a sitting posture when fully awake to hasten redistribution and absorption of the residual fluid. Severe coughing was controlled by positioning the patient with the lavaged lung in a dependent position.

Chest roentgenograms were obtained sequentially during lavage in four patients. Films were obtained in each patient at 6 and 24 hours postlavage. When a residual infiltrate was present 24 hours after lavage, films were repeated daily until infiltrates had disappeared. Perfusion lung scans were performed in each patient. The lung with the least perfusion was selected for the first lavage. Scans were repeated in three patients 24 hours after the lavage and in two patients 8 to 12 weeks later.

The effects of air trapping on blood gases and the yield of pulmonary lipid in the washings was tested in three patients by ventilating them with room air for ten minutes before degassing. For lipid analysis the washings were frozen shortly after their recovery and later lyophilized and extracted with chloroform. Extracts were then analyzed for total lipids and phospholipid.

RESULTS

Respiratory Studies

The PAO₂ fluctuated widely throughout the various phases of the lavage (Fig 1), but an oxygen saturation exceeding 90 percent was always maintained. The PAO₂ levels were lowest when the lung was drained, demonstrating increased intrapulmonic shunting. The lowest PAO₂ value obtained in 93 sequential determinations was 56 mm Hg. Following lavage, moderate to severe arterial hypoxemia was always present. It was most severe in the first two hours postlavage. After breathing air for five minutes, the lowest PAO₂ values recorded were 38 and 41 mm Hg. Postlavage hypoxemia, however, was readily controlled with supplemental oxygen. When approximately 40 percent oxygen was administered by IPPB, the two lowest PAO₂ measurements were 48 and 50 mm Hg.

Mild degrees of arterial hypercapnia occurred transiently in association with bronchospasm, during 4 of the 15 lavages (Fig 1). The highest PACO₂ was 60 mm Hg. In the postlavage periods, the PACO₂ exceeded 50 mm Hg in 7 of 93 determinations. Acute respiratory depression occurred immediately after the 11th lavage but adequate ventilation was established without intubation. Hypoventilation was invariably associated with the administration of concentrations of inspired oxygen exceeding 40 percent. Changes in the arterial pH did not always parallel changes in the PACO₂. A compensated metabolic acidosis, present before the first and second lavages became more apparent after alveolar hyperventilation; mild metabolic acidosis also developed during the seventh lavage.

Hemodynamic Studies

No significant untoward cardiovascular effects were associated with pulmonary lavage. Filling and draining of the lung did not affect the heart rate which varied from 60 to 120 beats per minute. Once anesthesia was begun, pulmonary and systemic arterial blood pressures were not influenced by mechanical manipulation of the lung or by changes in arterial blood gases. Even in case 5, where pulmonary hypertension was initially present (36/12 mm Hg), the pulmonary artery pressure did not rise when the lung was filled. Transient systemic hypertension (70 mm Hg systolic) occurred once during each of the first two lavages when rapid infusions of isoproterenol (1 mg/ml) were used to reverse bronchospasm.

Cardiac output fell after anesthesia was initiated. In two cases it showed a further drop when the lung was filled and an increase when the lung was drained (Fig 2). Cardiac output was always above control measurements when determined one hour postlavage in the presence of hypoxemia. Venous admixtures increased as the lung was drained in three of four instances, and after the lavage was completed (Fig 2).

Mechanical Events and Other Observations

Bronchospasm was common during the procedure. It was manifested by audible wheezing in the
Table 2—Volume of Infused and Recovered Solution, Its Lipid Composition and Rate of X-ray Resolution Postlavage

| Lavage* | Case | Vol of Irrigating Fluid | | Lipids in Washings | | Preoperative Ventilation | | Rate of Resolution by X-ray |
|---------|------|---------------------|------------------|----------------|-------------------|----------------|-----------------|
|         |      | Infused ml          | Recovered ml     | Total Lipid mg/100 ml | Phospholipid % total |                   | Days |
| 1       | 1    | 5,900               | 5,600            | 95% | 11.83 | 35.0 | O₂ | 2 |
| 2       | 1    | 2,000               | 1,200            | 60% | 5.53  | 31.0 | O₂ | 1 |
| 3       | 2    | 4,500               | 2,000            | 44% | 8.4   | 56.0 | O₂ | 1 |
| 4       | 2    | 4,400               | 2,600            | 59% | 3.64  | 31.0 | O₂ | 1 |
| 5       | 3    | 6,000               | 3,600            | 60% |                   |                   | O₂ | 3 |
| 6       | 4    | 6,000               | 3,400            | 57% |                   |                   | O₂ | 1 |
| 7       | 5    | 3,500               | 2,900            | 83% |                   |                   | O₂ | 2 |
| 8       | 5    | 3,500               | 2,200            | 66% |                   |                   | O₂ | 3 |
| 9       | 6    | 5,500               | 4,800            | 87% | 10.7  | 35.8 | O₂ | 1 |
| 10      | 7    | 6,200               | 5,500            | 89% |                   |                   | O₂ | 1 |
| 11      | 1    | 7,900               | 7,200            | 91% | 4.86  | 34.8 | O₂ | 1 |
| 12      | 1    | 1,500               | 1,200            | 80% | 7.16  | 63.6 | Air | 1 |
| 13      | 4    | 3,200               | 1,200            | 38% | 8.4   | 38.4 | O₂ | 1 |
| 14      | 4    | 3,300               | 2,600            | 79% | 6.16  | 68.5 | Air | 1 |
| 15      | 4    | 3,600               | 2,100            | 58% | 8.09  | 56.0 | Air | 1 |

*Lavages are numbered in chronologic order of their performance.

Ventilated lung, by failure of the lavaged lung to drain, and by an increase in the inspiratory pressure required to maintain a constant minute ventilation. Bronchospasm with trapping of fluid was relieved to a considerable degree by rapid intravenous administration of aminophylline.

From 0 to 86 percent of the fluid initially filling the lung was recovered during the first draining phase. Subsequent return of lavage fluid amounted to more than half the total fluid volume used in 13 of 15 lavages (Table 2). Numerous bronchial casts were removed from the asthmatic patients, but in the bronchitic patients casts were much less profuse. Bubbles of trapped gas were seen infrequently in the initial draining when the lung fluid was degassed for five minutes and frequently when the lung was degassed for only two minutes. When the lung to be lavaged was ventilated with room air prior to degassing, gas bubbles and froth appeared in the effluent throughout the lavage and the amount of pulmonary phospholipid removed, nearly doubled (Table 2). This experimental change in technique, however, was without clinical significance. None of the patients ventilated with air prior to degassing showed atelectasis or delayed resorption of the residual alveolar fluid.

Roentgenograms obtained during lavage demonstrated a decrease in lung volume of approximately 15 percent to 30 percent after degassing for five minutes. The decrease in lung volume was produced by a rising diaphragm and slight shift of the mediastinum. No segmental or plate-like atelectasis was noted. After degassing for two minutes, no definite reduction in lung volume was discernible. Initially, irrigating fluid filled the lung unevenly (Fig 3 A). With repeated filling and draining the

residual gas was eventually displaced (Fig. 3 B) and more homogenous filling of the lung was accomplished (Fig 3 C). Radiographic resolution of infiltrates was complete within 24 hours after 11 of 15 lavages (Table 2). In two of the three RISA scans repeated after lavage, increased radioactivity over previously underperfused areas was demonstrated. In case 5 increased perfusion was noted particularly over the right lower lobe area (Fig 4 B). Increased perfusion persisted to some extent after ten weeks (Fig 4 C) but had disappeared by 14 weeks.

**Long Term Results**

Six patients returned for repeated study. At the end of three months five still showed clinical improvement, with less dyspnea and fewer medication requirements, but only two demonstrated a clear-cut improvement in respiratory functions. A combination of intensive antibiotic therapy and pulmonary lavage failed to eradicate a chronic bronchial infection caused by *Pseudomonas aeruginosa* (case 5). By six months the asthmatic (case 1) had noted increased wheezing and by seven months the results of pulmonary function studies approached baseline values (Table 3). The improvement of the mild bronchitic (case 7) was sustained for ten months.

**Complications**

Pulmonary infiltrates persisted more than 24 hours after four lavages and were always associated with a fever. An asthmatic patient (case 1) who was lavaged during the 1968 influenza epidemic developed a flu-like illness six hours after the first lavage. A patient with asthmatic bronchitis (case 3) developed a fever and leukocytosis two days after the procedure and pneumococci were cultured from his sputum. The patient with a chronic bronchial infection, associated with a persistent heavy growth of *Pseudomonas aeruginosa* in the sputum (case 5), had tachycardia, dyspnea, chills and fever up to 104° F five hours after lavaging the right lung. A similar illness, accompanied by hypotension, was observed six hours after lavaging the left lung. Although large volumes of purulent secretions were expectorated at both times, repeated blood cultures
BRONCHOPULMONARY LAVAGE IN ASTHMA AND CHRONIC BRONCHITIS

**Table 3—Respiratory Function before and after Pulmonary Lavage**

<table>
<thead>
<tr>
<th>CASE 1</th>
<th>CASE 2</th>
<th>CASE 3</th>
<th>CASE 4</th>
<th>CASE 5</th>
<th>CASE 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>PaO2 (mm Hg)</td>
<td>VC</td>
<td>FEV1.0</td>
<td>PaO2</td>
<td>VC</td>
<td>FEV1.0</td>
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<tr>
<td>Before Lavage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Predicted</td>
<td>90</td>
<td>4.51</td>
<td>3.61</td>
<td>90</td>
<td>5.19</td>
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<tr>
<td>6-14 months</td>
<td>78</td>
<td>2.78</td>
<td>0.93</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1-2 weeks**</td>
<td>71</td>
<td>3.18</td>
<td>1.31</td>
<td>70</td>
<td>3.73</td>
</tr>
<tr>
<td>After Lavage</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>1-2 weeks</td>
<td>—</td>
<td>3.07</td>
<td>1.71</td>
<td>62</td>
<td>4.10</td>
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<tr>
<td>4-6 weeks</td>
<td>92</td>
<td>3.11</td>
<td>1.62</td>
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<td>12-16 weeks</td>
<td>85</td>
<td>3.84</td>
<td>1.69</td>
<td>65</td>
<td>3.82</td>
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<tr>
<td>29-43 weeks</td>
<td>75</td>
<td>3.16</td>
<td>1.69</td>
<td>66</td>
<td>—</td>
</tr>
</tbody>
</table>

**Maximal Values for each patient.**

**Baseline values.**

PaO2 = Arterial oxygen tension (mm Hg) Subject breathing room air

VC = Vital capacity in liters, BTPS

FEV1.0 = Forced expiratory volume in one second

Expressed in liters per second

fail to demonstrate bacteremia. The illnesses were treated with ampicillin and all patients were afebrile within 48 hours.

**COMMENTS**

Lavage of the entire lung can be safely accomplished in the presence of moderately severe obstructive airway disease. Hypoxemia is not a contraindication to the procedure because adequate oxygenation can be provided by ventilating one lung with 99 percent oxygen. On the other hand, because a further reduction in alveolar ventilation will occur during and after the lavage, hypercapnia is a contraindication to the procedure.

In these patients, monitoring of arterial blood gases with the aid of an indwelling arterial cannula was useful during lavage as a gauge of ventilation and was essential to therapy in the postlavage period, when moderate to severe hypoxemia prevailed. Low concentrations of supplemental oxygen were used in the postlavage period to prevent hypercapnia and avoid atelectasis in partially obstructed segments. A Ventimask or a nasal cannula was used for this purpose. In the first two hours postlavage the nasal cannula most effectively provided the constant supply of oxygen required, without interfering with coughing and expectoration. In the four instances when postlavage hypercapnia developed, extubation was premature or the oxygen flow excessive. Reintubation was never required but ventilation was assisted with IPPB. On two occasions this resulted in the rapid release of large amounts of trapped fluid and a sudden increase in alveolar ventilation.

Careful control of ventilation during lavage was important, not only to prevent hypercapnia, but also to prevent the emergence of metabolic acidosis from over-ventilation. Early in our experience, patients were hyperventilated and on four occasions, drops in pH were noted when the arterial PaCO2 was between 24 and 36 and the oxygen saturation exceeded 90 percent. The lowest pH in the arterial blood (7.29) was measured during the ventilatory phase preceding the second lavage when the PaCO2 was 36 mm Hg. Although lactic acid levels were not measured, the possibility that lactic acidosis was induced by hypocapnia must be considered.

By ventilating with ambient air prior to degassing, some insight into events occurring naturally with air trapping was obtained. Initially the egress of fluid was mechanically hindered by the large air bubbles returning with the effluent; the amounts of pulmonary phospholipid (? surfactant) recovered in the effluent was nearly doubled. Nevertheless, neither the mechanical differences created by this experimental maneuver nor the increased amount of phospholipid obtained were physiologically important: the period of postlavage hypoxemia was not prolonged; clearing shown on the chest films in three lavages was completed in 24 hours.

Pulmonary scans showed in two patients increased perfusion of areas of lung parenchyma even though pulmonary function did not improve. The improvement in perfusion probably was secondary to improved ventilation of obstructed lung segments, as postulated by Bergofsky and co-workers. Perfusion scanning, because of its simplicity, merits further evaluation as another objective method of gauging improvement.

Although the arterial oxygen tensions were lower with the lung drained than with the lung filled,
progressive hypoxemia with repeated filling of the lung was not observed. It is possible that the drop in oxygen tension reported by Wasserman and colleagues\(^6\) resulted from events occurring outside the lavaged lung. Minimal but repeated spillage of fluid into the ventilated lung at peak filling pressures is difficult to detect and could well account for progressive hypoxemia.

In a study of 65 patients, Birley\(^4\) has compared a modification of this technique with segmental lavage through a bronchoscope as proposed by Thompson and Prior.\(^15\) She deemed this technique preferable because it provided a better control of ventilation and appeared to reach deeper into the lung. Lavage using a bronchspirometric tube after partial degassing yielded a predominance of pigment-laden alveolar macrophages rather than bronchial epithelial cells. Further evidence that very small airways are cleaned by this method has been obtained by demonstrating bronchial casts of less than 0.2 mm in diameter in lung washings of patients with alveolar proteinosis.\(^16\)

Patients with chronic bronchitis and asthma have a widely variable clinical course. For this reason, in a small series any evidence of improvement must be interpreted with caution. The initial clinical response obtained in five patients is encouraging, but the limited and short-lived physiologic improvement in only two cases suggests that the procedure may be applicable only in special and not yet well-defined circumstances.

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