A Rebreather for Prophylaxis and Treatment of Postoperative Respiratory Complications*

RICHARD H. ADLER, M.D., F.C.C.P.

Buffalo, New York

Postoperative respiratory complications continue to be a problem of general concern. There has been a decrease in the mortality rate and a drop in the number of spectacular complications previously seen due to improvements in modern treatment. As a result, many surgeons not regularly involved with respiratory problems fail to appreciate the continuing high incidence of postoperative respiratory complications and the morbidity associated with them.

When atelectasis or pneumonitis become clinically apparent, a variety of therapeutic measures are brought to bear on the patient such as: antibiotics, mucolytic agents and aerosol mixtures with IPPB, intratracheal lavage and suction, CO₂ inhalation, rebreathing devices, blow bottles, intercostal nerve blocks, chest physiotherapy, bronchoscopy, and tracheostomy. Today, the patient will usually survive the complication, but at a significantly increased expense, prolonged hospitalization, and time drained from hard-pressed hospital personnel. This extra cost and morbidity may not be fully apparent to the busy clinician.

It is common practice for the surgeon to order, “deep breathe and cough every hour” in an effort to counteract the restricted ventilation and patient immobility commonly encountered after many major operations. Unfortunately, the professional and paramedical personnel seldom have time to carry out this order properly. Instead, one finds a variety of methods in use partly to meet this need and partly because of the general fascination that exists for devices and machinery.

The incidence of postoperative respiratory complications is significantly elevated in association with a number of factors such as obesity, old age, serious preoperative illness, duration of anesthesia, chronic cigarette smoking, inadequate postoperative care, and pre-existing respiratory disease. For example, in a recent study by Stein et al., over two-thirds of patients with chronic bronchitis and emphysema developed atelectasis and pneumonia postoperatively. Unfortunately, the clinician may not appreciate the presence of chronic bronchopulmonary disease, since many patients tend to minimize chronic symptoms such as sputum, cough, and even mild exertional dyspnea. In addition, it is difficult clinically to detect and to evaluate existing respiratory disease as attested to by the number of pulmonary function tests that have been proposed.

The type of surgery and sites of incisions also influence the development of postoperative respiratory complications. Anscombe, Ross et al., as well as others have demonstrated the marked reductions of respiratory mechanics following abdominal and hernia surgery. Although postoperative respiratory complications are commonly thought of in association with surgery performed on the abdomen and thorax, it is of interest to note the recent comments by Bendixen et al. of a 10 to 30 per cent incidence of clinically detectable atelectasis and pneumonia following surgery on the extremities. A sobering comment in a relatively recent literature review of postoperative respiratory complications was, “A most startling observation studying reviews of atelectasis is the absence of any evidence of reduction in the incidence of this complication.”

CO₂ Inhalation and Dead Space Rebreathing Devices

Inhaling CO₂ is well recognized as a means of producing hyperventilation.
Breathing CO₂ from a tank is cumbersome and involves trained help and additional expense. Rebreathing one's own exhaled air is simple, and it will effectively elevate the alveolar and blood CO₂ thereby stimulating deep breathing. Rebreathing into a paper bag has had appeal because of its simplicity, but it has proved to be unsatisfactory because of its poor fit on the face, its small content of oxygen, and its limited size relative to the increasing volume of ventilation. Rebreathing through an open-end vessel to promote deep breathing has also attracted sporadic attention in the past.

In 1957, Schwartz et al. reported studies documenting hyperventilation in response to elevated alveolar CO₂ levels when subjects rebreathed through a long one liter capacity tube. Use of this cylindrical cardboard tube known as the Dale Schwartz rebreathing tube has become a part of the postoperative routine at the Strong Memorial Hospital and Rochester Municipal Hospital. In 1960, Darin et al. reported a controlled clinical study further demonstrating the value of the postoperative use of the Dale Schwartz rebreathing tube. In patients undergoing biliary tract surgery, there was a 68 per cent incidence of atelectasis as demonstrated clinically or by x-ray in the control group as compared to only a 14 per cent incidence in the group of patients using the Dale Schwartz rebreathing tube.

The Dale Schwartz rebreathing tube has been in use at the Buffalo General Hospital for five years. During this time, it became increasingly evident that the tube was not being used properly due in part to improper understanding of its function by some of the hospital personnel. More important, however, was the general lack of patient acceptance of the tube. A more formal hospital survey showed that many tubes stood on the floor or lay on window sills or dressing tables beyond the reach of patients in bed. Some patients found other uses for the tube such as moving bedside curtains and adjusting knobs on television sets. Recently, one patient was found to have cut more than half the length off the 42 inch long tube so that it would set on the bedside table.

The rebreather to be described emerged from the need to develop a more acceptable yet simple rebreathing device that could be easily handled and correctly used by patients without continual need for assistance from another person (Fig. 1). The rebreather* is a compact five by seven inch, four ounce plastic device open at either end. The inside is compartmented by walls containing openings remotely located from one another so that air is thoroughly mixed during the period of rebreathing. Pressure measurements have confirmed the practical lack of resistance to air flow. A constant air flow of 12 liters per minute through the rebreather produces no pressure deflection in a water manometer connected to a side arm just proximal to the rebreather mouthpiece. Measurements taken on patients during the height of hyperventilation through the rebreather showed average pressure fluctuations of 1 or 2 cm of water.

The rebreather has an adjustable polyethylene mouthpiece designed to fit the mouths of patients without discomfort or air leak. The unit includes a plastic covered metal noseclip that eliminates the need to compress manually the nose by a nurse or technician during rebreathing. The rebreather sets conveniently on the bedside table rather than on the floor, and it is easily reached by the patient in bed. It has an effective volume of 1 liter; the same as that of the Dale Schwartz rebreathing tube.

Comparison of the Rebreather and the Rebreathing Tube

Initially, 21 normal individuals essentially unfamiliar with rebreathing devices were subjected to five minute rebreathing periods with each device. The subjects received no indoctrination, and efforts were made to avoid influencing their breathing pattern. Determinations included minute volumes, average minute tidal volumes, and respiratory rates. The results (Fig. 3) showed that the rebreather produced essentially the same hyperventilatory response as seen with the Dale Schwartz rebreathing tube. The rebreather was then subjected to further study and clinical usage.

Methods

Ventilography—A system was devised modified from the "bag-in-box" principle which permitted accurate ventilography using a portable very low resistance closed circuit system. In essence, this consisted of an airtight 55 gallon metal drum with a plastic window, a thin-wall 120 liter capacity Neoprene balloon suspended from the inspiration pipe inside the drum, and a modified 9 liter Collins respirometer for recording ventilatory excursions.

With the patient supine, five-minute long ventilograms were obtained before and after the rebreather was introduced into the recording system allowing a complete rest between recordings. In selected patients, the ventilograms were repeated with the Neoprene bag filled with oxygen rather than room air. Many patients studied in the laboratory had ventilation additionally monitored by pneumogram belts placed around the lower chest and mid-abdomen.

Arterial blood determinations—In 38 selected patients, multiple preoperative and postoperative arterial blood samples were analyzed for pH, CO₂ tension (PaCO₂), O₂ tension (PaO₂) and O₂ saturation. Instrumentation laboratory equipment was used with a modified Clarke O₂ electrode, a Severinghaus CO₂ electrode and a glass
After obtaining a resting arterial blood sample, accurately timed brachial artery samples were withdrawn at the end of the second, third, and fifth minutes during the five-minute period using the rebreather. Another arterial blood sample was taken routinely five minutes after discontinuing use of the rebreather with the patient remaining supine and quietly breathing room air. This procedure was repeated in selected patients using the rebreather with oxygen in the Neoprene bag or with an oxygen catheter inserted into the open end of the rebreather. In the latter situation, the ventilatory pattern was monitored by the pneumograph belts which were connected to a sensitive electronic recorder (Honeywell 1508 multi-channel Visicorder).

Surgical patients—A total of 118 patients with an age span from 16 to 82 years were studied with the rebreather-ventiilogram system preoperatively and for a minimum of three days following surgery (Table 1). Thirty-eight of this group had concomitant arterial blood studies outlined above. The 27 miscellaneous operations including a variety of vascular, proctologic, orthopedic, and gynecologic operations with periods of anesthesia lasting at least one hour. An additional 130 patients undergoing major surgery but not studied with the ventiilogram system or by arterial blood determinations were given the rebreather for hourly use. Each patient receiving the rebreather had an evaluation sheet placed on the hospital chart which was completed by the floor nurse before the patient was discharged.

**RESULTS**

Ventilation—The average minute tidal volume almost always increased to at least twice the average resting level after using the rebreather for three minutes with a variable additional increase during the next two minutes of rebreathing. Some frail or seriously ill patients could complete only two or three minutes of rebreathing during the immediate postoperative period because of exhaustion.

The most striking finding on the ventiilogram during the use of the rebreather was the unpredictable occurrence of intermittent deep breaths some over three and four times as deep as the resting tidal volume (Fig. 4). These greatly augmented inspirations could occur during intervals when the average tidal volume was approaching only twice that of the average resting tidal volume. Also, of interest was the distinctly individual breathing pattern noticed among some patients both before and after surgery.

The respiratory rate usually had an insignificant rise during use of the rebreather; the increased minute volume being due to

**TABLE 1—Operations with Rebreather—Ventiilography System**

<table>
<thead>
<tr>
<th>Operation</th>
<th>No. Patients</th>
</tr>
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<tbody>
<tr>
<td>Abdominal surgery</td>
<td>60</td>
</tr>
<tr>
<td>Biliary tract</td>
<td>23</td>
</tr>
<tr>
<td>Gastric and hiatal hernia</td>
<td>9</td>
</tr>
<tr>
<td>Laparotomies</td>
<td>28</td>
</tr>
<tr>
<td>Herniorrhapies</td>
<td>21</td>
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<tr>
<td>Inguinal</td>
<td>18</td>
</tr>
<tr>
<td>Ventral incisional</td>
<td>3</td>
</tr>
<tr>
<td>Thoracic surgery</td>
<td>10</td>
</tr>
<tr>
<td>Open heart</td>
<td>3</td>
</tr>
<tr>
<td>Major thoracotomies</td>
<td>7</td>
</tr>
<tr>
<td>Miscellaneous*</td>
<td>27</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>118</strong></td>
</tr>
</tbody>
</table>

**FIGURE 4:** Ventiilogram of a 48-year-old woman using rebreather before and after laparotomy. Augmented intermittent deep breaths far exceed the average minute tidal volumes. A distinctly individual breathing pattern is apparent.
the increased tidal volume. A small but distinct group of tense patients with painful upper abdominal and thoracic incisions responded to the rebreather during the early postoperative period with an unusual rise in respiratory rate and a lessened increase in tidal volume. Reassurance with a reminder to breathe more slowly and the use of medication for relief of pain commonly corrected this uncommon response to the rebreather.

The administration of standard postoperative doses of meperidine (Demerol) for pain frequently resulted in deeper breathing with use of the rebreather. Although meperidine, like morphine, has been regarded as a respiratory depressant, it improved the ventilatory response to the rebreather when pain and muscle splinting were restricting the depth of ventilation.

The pneumogram belt recordings were less accurate than the ventilograms, particularly following surgery and commonly failed to transmit the true amplitude of the intermittent deep breaths seen with the ventilogram. Simultaneous use of a thoracic belt and an abdominal belt demonstrated the shifts in abdominal and thoracic breathing patterns in the supine patient who had a thoracic incision or an abdominal incision.

Arterial blood studies—Most individuals had a roughly parallel rise in arterial CO$_2$ tension and tidal volume with a mild fall in arterial pH during the five-minute use of the rebreather (Fig. 5). The rise in CO$_2$ tension averaged six to eight mm Hg with a range from 1 to 12 mm Hg. Almost all resting pH values were between 7.35 and 7.45. In most individuals the pH fall during rebreathing ranged between 0.03 and 0.08. In patients with resting arterial oxygen tensions over 90 mm Hg, the level commonly fell 15 to 20 mm Hg during the first two minutes of rebreathing. The arterial oxygen tension usually rose by the fifth minute of rebreathing, the rise varying with the increase in ventilation. The oxygen saturation, however, fell comparatively little during the rebreathing period. In almost all patients, the arterial blood values were back to the resting levels five minutes after discontinuing use of the rebreather.

Inserting an oxygen catheter into the open end of the rebreather eliminated any fall in arterial O$_2$ tension. An oxygen flow rate of approximately 3 liters per minute resulted in rising arterial O$_2$ tension levels above the so-called normal range without significantly changing the increased ventilatory response associated with use of the rebreather.

Low resting arterial oxygen tensions were common particularly in older patients after surgery and in a surprising number of patients before surgery. PaO$_2$ values from 85 to 70 mm Hg were not uncommon in patients over 55 years of age. Patients with low resting arterial O$_2$ tensions had little or no fall in the PaO$_2$ during use of the rebreather.

Of the 38 patients followed with arterial blood studies, 14 had a rise in PaO$_2$ during or following use of the rebreather breathing room air. With one exception,
this rise occurred in patients with low resting arterial \( O_2 \) tensions. Eight of the 14 patients showed a variable, but significant decrease in the alveolar-arterial (A-a) oxygen gradient from the resting level following use of the rebreather. The relatively small number of patients studied to date, however, permits no conclusions as to how long the improved oxygen tensions are sustained. The many variables encountered among patients during the postoperative period necessitated each patient serving as his own control.

COMMENTS
The rebreather evaluated in this study produced essentially the same hyperventilatory response as noted with the long cylindrical Dale Schwartz rebreathing tube. Because of its compact and more practical design, however, the rebreather was readily used by patients and enthusiastically accepted by hospital personnel. Most patients quickly grasped the principle of its function and correct usage. Patients were motivated to use it without assistance particularly when they received the rebreather preoperatively along with a short period of instruction by an interested individual. The accompanying noseclip eliminated the need to have someone compress the nostrils, and the few simple instructions printed on the rebreather helped the forgetful patient remember its proper usage. Patient movement associated with reaching for and using the rebreather helped promote the desired “stir-up” regimen following surgery. Also, the presence of the rebreather on the bedside table appeared to have a psychological effect on many patients by periodically focusing their attention on their breathing and coughing.

The specially designed large portable ventilogram apparatus into which the rebreather could be attached to record breathing patterns demonstrated the progressive increase in depth of ventilation with only a minor increase in rate of ventilation. A finding of particular interest shown by this apparatus during use of the rebreather was the unsuspected periodic deep breaths, some of which were over three or four times as deep as the average resting tidal volumes. These irregular deep breaths varied among patients for reasons not understood, but they often tended to form a distinctive repetitive part of an individual's breathing pattern during use of the rebreather.

The normal individual, even when resting quietly, will spontaneously take about eight to ten deep breaths per hour. These beneficial deep breaths have been referred to as sighs or inspirations approximately three times that of the resting tidal volume. Periodic deep breaths promote proper air distribution and alveolar fill. Following surgery, however, an abnormal pattern of relatively uniform shallow breathing is commonly seen which sets the stage for the development of atelectasis and pneumonitis.

Morphine in doses equivalent to that administered for postoperative pain has also been shown to eliminate normal spontaneous sighs. Our studies show that meperidine (Demerol) in doses equivalent to that of morphine will aid the deep breathing associated with use of the rebreather by lessening pain particularly in association with upper abdominal and thoracic incisions.

The deep breathing induced by the rebreather following major surgery appears to have several beneficial effects. By expanding the lung and opening collapsed or poorly ventilated alveoli, the common subclinical changes of the more recently appreciated diffuse or miliary form of atelectasis are reversed. Without periodic stretching or opening of unaerated alveoli, the surfactant material normally lining alveoli which helps prevent atelectasis by maintaining geometric stability in alveolar size will “age.” This leads to a loss of pulmonary compliance and the development of a stiffer lung which becomes progressively difficult to inflate with time. As a result, greater patient effort or increased airway pressure is necessary to expand the collapsed and shrunken alveoli. Increased airway pressures from ventilators may actually shunt blood away from some remain-
ing open alveoli thereby further aggravating the situation.

Atelectasis after surgery results in variable degrees of hypoxemia when normal pulmonary blood flow perfuses collapsed and poorly ventilated alveoli. Our studies with the rebreather are in agreement with others who have shown the benefit of deep breaths in reversing postoperative arterial hypoxia. Hamilton et al have recently reported on the postoperative use of a dead space rebreathing apparatus consisting of a face mask with an attached length of corrugated rubber tubing as used by anesthesiologists. The hyperventilation induced by this dead space rebreathing apparatus was associated with an elevation in the \( \text{O}_2 \) tension of all patients with a decreased postoperative arterial \( \text{O}_2 \) tension. The highest rise was 35 mm Hg. Giebel also found an increase in \( \text{PaO}_2 \) after use of a rebreathing tube plus a decrease in the alveolar-arterial \( \text{O}_2 \) gradient suggesting that collapsed air spaces had been opened by the hyperventilation produced by his dead space rebreathing tube.

Although a temporary fall in oxygen tension from "normal" high levels has been noted during the first several minutes' use of a 1 liter rebreathing device, this is usually returning well back toward normal at the end of five minutes of rebreathing room air. Actually, there is an insignificant drop in oxygen saturation during use of the rebreather. In the patients with low resting arterial oxygen tension, however, we found little or no fall in oxygen tension in association with the use of the rebreather, and an actual rise in \( \text{O}_2 \) tension in many patients. Nevertheless, if one is concerned about a drop in normal arterial oxygen tension, this can be eliminated by inserting a catheter into the open end of the rebreather with a flow rate of oxygen at 3 liters per minute. This does not disturb the hyperventilatory effects associated with rebreathing.

Coughing is frequently induced by the rebreather particularly in patients with increased bronchial secretions. Opening bronchi obstructed by retained secretions relieves the classic clinically recognizable form of atelectasis and prevents the pneumonitis that so commonly follows if the atelectasis persists. Others have also commented on the stimulation of secretion loosening coughing with use of rebreathing devices.

The rebreather may be effective as a prophylactic measure alone, or it can be used in treating established respiratory complications in conjunction with other popular methods in use today. Despite its attractive features, however, the rebreather cannot be merely handed to any patient without instruction and an occasional follow-up visit with the expectation of ideal results. Also, the rebreather will not help the severely emphysematous patient with a significantly elevated \( \text{PaCO}_2 \) level or cor pulmonale. Nor will it help the exhausted or feeble patient who needs to have the work of breathing taken over by some form of mechanical assistance.

The rebreather presented here, therefore, does not represent a panacea for preventing or curing postoperative respiratory complications. It does offer a simple and effective device for decreasing the incidence of these common complications. Of particular importance is the fact that the patient can be readily taught to help himself without need for assistance.

**Summary**

The incidence of atelectasis following major surgery remains practically unchanged. Of the many methods in use for the prevention and treatment of postoperative respiratory complications, a dead space rebreathing device has appeal because of its simplicity and effectiveness. The new rebreather presented here is a light compact rebreathing device of 1,000 ml capacity that patients find to be effective and easy to use without assistance. Arterial blood studies and ventilation recordings show an increased depth of breathing in response to the rise in arterial \( \text{CO}_2 \) tension during use of the rebreather. Very deep intermittent breaths are commonly encountered with use of the rebreather. Periodic
deep breaths effectively counteract the quiet shallow breathing pattern predisposing patients to the development of atelectasis and pneumonia. The improved oxygenation seen in many patients with low resting arterial oxygen tensions suggests that deep breaths open collapsed alveoli.

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RESUMEN
La incidencia de la atelectasia post operatoria consecutiva a la cirugía torácica mayor sigue siendo prácticamente invariable.

De todos los métodos usuales en la prevención y el tratamiento de las complicaciones respiratorias de la cirugía, el sistema a base de respiración en un espacio confinado continua siendo favorecido debido a su sencillez y efectividad. Presentamos un nuevo dispositivo ligero y compacto, de 1000 c.c. de capacidad, considerado por los pacientes como efectivo y fácil, sin necesidad de ayuda. Los estudios de la sangre arterial y ventilación demuestran un aumento en la amplitud de los movimientos respiratorios resultantes de la elevación de la tensión del CO₂ arterial durante su uso, observándose inspiraciones periódicas muy profundas. Estos movimientos profundos y periódicos contrarrestan la tendencia a la respiración superficial, con expansión torácica limitada, que predispone a la atelectasia y la neumonía.

El aumento en la oxigenación observado en muchos pacientes parece indicar que la respiración profunda contrarresta el colapso alveolar.

ZUSAMMENFASSUNG

Die bei vielen Patienten mit einer niedrigen arteriellen O₂-Spannung in der Ruhe festgestellte verbesserte Sauerstoffsättigung lässt annehmen, dass tiefe Atemzüge die kollabierten Alveolen öffnen.

REFERENCES

For reprints, please write: Dr. Adler, 100 High Street, Buffalo, New York 14205.