The Respiratory Care Unit

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This contribution will be limited to a discussion of the need for respiratory care units and the organization of these units. In order to clarify why it is advisable to organize such a unit, with facilities for prolonged intermittent positive pressure ventilation (IPPV) in every large hospital, a short discussion of indications for and results with prolonged controlled ventilation is necessary. These indications have been worked out in many centers, but because of previous shortcomings in technical details and equipment, this kind of treatment has often failed to help the patient. Finally, some details of technique and equipment, which in our experience have been important, will be discussed. A discussion of equipment and methods for artificial ventilation in cases of chronic respiratory insufficiency, e.g., poliomyelitis, will not be included.

Background for Creation of Respiratory Care Units

Experience derived from the epidemic of poliomyelitis in Copenhagen in 1952, gave the impetus for an expansion of respiratory treatment to all patients with severe respiratory difficulties and led to an attempt to concentrate this treatment in special hospital units. Anesthesiologists have taken an active part in this development. Because of their special competence in supporting respiration and circulation, they have contributed to the planning of and often taken responsibility for respiratory care units.

The development of postoperative care also has contributed to the anesthesiologist being entrusted with the care of such units. The effectiveness with which therapy was administered in shock and resuscitation units of front line hospitals in World War II led to the introduction of similar units in civilian hospitals. Supervision of the newly operated patient is dominated, of course, by respiratory care in which the staff of "recovery rooms" has gained wide experience.

Following the good results of tracheostomy and IPPV in poliomyelitis, this method of treatment was used for patients with established or anticipated ventilatory deficiency after major thoracic surgical procedures, thoracic injuries or complications after abdominal operations. For better use of the necessary apparatus for respiratory treatment, it was natural that this method of treatment was coupled to recovery rooms in many centers.

For the same reasons, recovery rooms have developed into or been combined with "intensive care units" to which critically ill patients in need of expert supervision and intensive treatment could be sent from every department in the hospital.

Since respirator treatment in many cases is an important part of intensive care, the respiratory care unit should be identical with or a part of the intensive care unit. What these units are called is of minor significance; however, it is important that patients needing a particular kind of treatment, independent of the basic illness, should be concentrated in a unit, the staff and equipment of which are specially oriented to this kind of care. By this means, the results obtained from respirator treatment have improved. However, the formation of such units need not imply that personal physicians should be deprived of the care of their patients. It does imply that the specialist in the hospital comes to see the critically ill patient rather than the latter being brought to him. Used properly, these units can be the meeting place for different medical disciplines and can play an important role in present-day specialized medicine.

Administration of the Respiratory Care Unit

The direct responsibility for the patients in a respiratory care unit and the administration
of a unit has been much discussed, and in many places this may have been an obstacle for its creation. However, in our experience this obstacle can be eliminated easily if a policy similar to that in recovery rooms is adopted. Every physician referring a case to the intensive or respiratory care unit is still in charge of that patient. The patient belongs to the referring department, to which he is sent back when the need for special care is over. In the intensive care unit the anesthesiologist works as consultant for respiratory and circulatory emergencies in the same manner as he fulfills these duties in the preoperative and peroperative periods. As in the operating theater area, he must be there for immediate service to the patient. As the nursing staff of such units must have technical skill in eliminating airway obstruction and in supervision of controlled ventilation, an anesthesiologist is their natural teacher and supervisor. Administratively such a unit, therefore, can belong either to the department of anesthesiology or, if one clinical department is the "main consumer" of the unit, to that special department.

Organization of a Respiratory Care Unit

In 1958, two recovery room-intensive care units were established in the surgical block at Uppsala University Hospital (1,088 beds). In one there is room for 13 patients, nine in an open recovery room and four in single bed rooms, and it is administered by the Department of Anesthesiology. The other is part of the Department of Thoracic Surgery and has 11 beds, two 5-bed rooms and one single-bed emergency room. This latter unit exclusively serves patients with thoracic or vascular surgical or accidental trauma, but the Department of Anesthesiology also takes an active part in the care here, e.g., the anesthetic residents share the duty for the two units with their surgical colleagues. Because of shortage of qualified nurses, only five specialist nurses each with 45 working hours per week are available in each unit. They have, however, help from six orderlies in each unit and from so-called respirator-attendants. The latter are laymen, who have previously received a special course in the function of the respirator and in the performance of necessary routine checks such as recording of respiratory minute volume, insufflation pressure, arterial blood pressure, pulse rate, and change in posture. Physiotherapists are available for the important breathing exercises.

In both units all beds are supplied with piped oxygen and compressed air (for suction) and there are facilities for continuous recording of arterial pressure, ECG, EEG and temperature. Round the clock service for instant measurement of acid-base and oxygen tension in arterial blood by Astrup's electrometric technique and a modified Clarke electrode is available in an adjacent laboratory area, where spirometer tests also can be carried out. At the present time we have eight Engström respirators, which is now the only type used when prolonged controlled ventilation is indicated. Therm-O-Rite mattresses are used for cooling in hyperthermic cases or when hypothermia is indicated.

A further detailed description of equipment necessary for intensive care is unnecessary. It is of more value to point out two main shortcomings of these provisional units.

1) There is a constant need for isolation rooms in a unit, to which patients come from all over the hospital, possibly augmenting the already increasing danger of nosocomial infections. This is so even if, as in our case, there is a special hospital for communicable diseases. With respirator care in isolated rooms, the demands made on technical means for centralized supervision will increase, to avoid an unrealistic number of skilled staff. Fifty per cent of mankind cannot be used to nurse the other 50 per cent, even if it sometimes looks as if this is the trend. Single-bed rooms would also facilitate necessary visits from relatives.

2) Our units are in need of more staff. There should be at least one specialist nurse available at all times for every two patients on respirators.

The plan in figure 1 is based on experience derived from intensive-respiratory care units and is offered as one possible solution to the problem.

Evolution of Methods for Respirator Treatment

Until the late 1940's, respirator treatment for prolonged respiratory insufficiency was used only in poliomyelitis. Here the body
Cuirass respirators were employed with good results in cases of ventilatory insufficiency of spinal origin, whereas the results in patients with involvement of the lower cranial nerves and the bulbar centers were poor. The reason for this was the difficulty in keeping the airway free from secretions which diminished the efficiency of the respirator and caused pulmonary complications. The addition of a tracheostomy meant a real advance. But pulmonary complications could not be effectively prevented until the tracheostomy tube was supplied with a cuff to seal off the lower airways from the danger of aspiration. The failure to use a cuff and thus the inability to prevent airway complications may be the reason why tracheostomy did not gain more wide acceptance. When clinical respiratory physiologists advocated the use of respirator treatment in patients with pulmonary emphysema and ventilatory insufficiency aggravated by oxygen therapy, clinicians seemed to have been reluctant to perform a tracheotomy. It is, however, obvious that upper airway obstruction or “skillful use of the patient’s glottis” often prevented the ventilation from being effective. The use of a cuffed endotracheal tube greatly improved the gas exchange in these patients.

In addition to keeping the airway free and preventing pulmonary complications, a tracheal tube also makes the prolonged use of IPPV possible, and in our experience, this is the only kind of respirator treatment possible in patients with increased airway resistance and/or decreased lung-thorax compliance.

When respirator treatment was extended to conscious and semicomatose patients in need of ventilatory support, the inability of the patient to synchronize his breathing with the machine became obvious. The most important factor in eliminating dyspnea in these patients and thus in stopping them from fighting the machine, is to have a high enough
inspiratory flow rate. Motley et al.\textsuperscript{25} found it necessary to have 80–120 liters per minute peak flows in order to eliminate the negative phase in the beginning of inspiration owing to additional inspiratory effort. These high flows are difficult to achieve with tank and cuirass respirators, which in addition are impossible to use in patients in need of free movement and easy access to the body. Many currently-used respirators for IPPV also fail to produce the high flow-rates.\textsuperscript{33} A respirator must also fulfill certain other demands in order to give safe and effective ventilation of the patient’s lungs without impairing his circulation. It must give a suitable distribution of the necessary gas volume at lowest possible mean alveolar pressure.\textsuperscript{25,31,35} Different types of respirators are described elsewhere in this symposium. We have found that the volume-controlled Engström respirator,\textsuperscript{2,5,20,26,37} which delivers an accelerating flow with a possible peak velocity as high as 360 liters/minute, meets all the demands that must be put on a respirator. It is well tolerated without the use of relaxants or heavy sedation even by fully conscious patients. Relaxant drugs are used only in convulsive diseases. We have described previously the main characteristics of this respirator.\textsuperscript{8} In extrapulmonary ventilatory deficiency many types of respirators can be used, but in our experience in patients with gross intrapulmonary disturbances, the Engström respirator is the best type available.

As the aim of all respirator treatment is to provide the patient with sufficient ventilation, a volume-limited, pressure-variable machine, which independently of small changes in lung-thorax compliance and airway resistance, will deliver a predetermined respiratory minute volume to the patient, it must be preferred to a pressure-limited, volume-variable machine. This has been shown during anesthesia\textsuperscript{43} and is even more important in prolonged respirator treatment, where it is impossible to readjust the controls of pressure-limited devices repeatedly in order to maintain a constant ventilation. Slight hyperventilation helps in synchronizing the patient’s breathing with the respirator and in eliminating his spontaneous respiration.\textsuperscript{44} We have seen no ill effects of keeping patients in alkalotic apnea for long periods of respirator treatment. On the contrary, they are comfortable and rest better.\textsuperscript{19} This is one reason why patient-triggered respirators are less suitable in acute phases of respiratory distress.

The liberal use of tracheostomy withuffed tubes and access to a respirator, which is reliable and easy to control and well tolerated by even conscious and nonparalyzed patients, are essential if all patients in need of ventilatory support are to be helped.

Indications and Results in Intermittent Positive Pressure Ventilation

The reader is referred to two previous papers\textsuperscript{8,41} in which our indications and results have been given following prolonged controlled ventilation with the Engström respirator. Table 1 gives our material from 1961. There has been a steady increase in the use of prolonged respirator treatment. As our indications for the use of tracheostomy with IPPV may be wider than elsewhere, the following comments will be added.

Obvious indications for respirator treatment are raised arterial carbon dioxide tension due to acute ventilatory insufficiency or decompensated respiratory acidosis and CO\textsubscript{2}-narcosis due to superadded infection in chronic pulmonary disease (table 1, 1–10).

Less obvious may be the indications for respirator treatment in the postoperative phase and they may call for explanation. The abdominal cases (table 1, 11a) were seriously ill patients. Most of them had undergone emergency surgical procedures. In 13 of them the respirator treatment was started only when the patient was moribund with manifest respiratory and circulatory failure. It was possible to save three of these. In 18 of them, tracheotomy was performed and respirator treatment started at the end of operation. All these patients were old, with small respiratory reserve and often with a previous history of cardiac deficiency. Some of them had metabolic acidosis and it was predicted that the respiratory work would become intolerable in the postoperative period. Eleven of these patients survived. To demonstrate the need for respirator treatment the following representative case is presented:
An 86-year-old woman with emphysematous lungs (at previous hospitalization MBC 45 liters/minute, and FEV1 only 45 per cent of the FVC) was admitted for acute cholecystitis with high fever. She was dyspneic with signs of broncho-pneumonia in the right lower lobe, but had normal acid-base values. A perforated, gangrenous gall-bladder which was surrounded by local peritonitis was removed and tracheotomy performed at the end of the operation. The first two postoperative days she was oliguric with a rise in nonprotein nitrogen to 93 mg/100 ml. and a metabolic acidosis, which was only compensated for by artificial ventilation. When the respirator was disconnected there was an immediate rise in arterial carbon dioxide tension (Paco2) and a fall in arterial oxygen tension (Pao2) below normal level. On the third day the kidney function improved and after four days she could breathe on her own without a rise in the Paco2. She was then only intermittently supported by the respirator, which could be completely omitted after six days. She made an uneventful recovery.

It is of vital importance to judge whether the patient is able to cope with an increase in respiratory work. In patients with reduced respiratory capacity, the oxygen consumption of the respiratory muscles increases rapidly at relatively low ventilation rates.42 It may reach 6-10 ml. O2/liter ventilation at rates of only 20 liters/minute.43,44 For this reason, these patients, even at rest, may have reached the level of ventilation above which the CO2 production of the respiratory muscles exceeds the volume of CO2 eliminated by further increases in ventilation. As a result, any further increase in ventilatory effort will cause a rise in PaCO2. Any further demand on CO2 elimination, e.g., to compensate for a metabolic acidosis, cannot be met. Without respirator treatment the patient will go rapidly into respiratory insufficiency with circulatory collapse.46 To relieve the patient of the intolerable respiratory work it is necessary to use a respirator, with which the patient has no difficulties in synchronizing his own respiratory efforts.

The indications for "prophylactic" respirator treatment in pulmonary surgery (table 1, IIb) have been low preoperative MBC, bilateral simultaneous lung resection for tuberculous cavities,47 partial resection of the only remaining lung and pulmonary resection in cases with restricted ventilation of the contralateral lung. During the three-year period (1958-1960)48 respirator treatment was given to 33 patients in connection with pulmonary surgical procedures with 27 survivals, and in 1961, 15 patients received treatment, with 12 survivals.

There has also been an increasing use of "prophylactic" respirator treatment after cardiac operations. The main indication has been pulmonary vascular hypertension with lung fibrosis. Preoperatively these patients have increased respiratory work49 and sub-normal Pao2. The thoracotomy further increases the respiratory work50 and in addition disturbed ventilation-perfusion ratios owing to atelectasis and uneven ventilation decrease the Pao2. A carefully nursed airway after tracheotomy helps to prevent stagnation of secretions and IPPV gives a more uniform ventilation.51 A slight expiratory resistance can easily be added if pulmonary edema is imminent. In cardiac cases, therefore, the decrease in Pao2 is often the indication for IPPV. Oxygen therapy alone will not help in preventing the development of dangerous degrees of shunting of blood in the lungs.

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**Table 1. Prolonged Intermittent Positive Pressure Ventilation (Range 1–20 Days, Average 4 Days)**

<table>
<thead>
<tr>
<th>Indications</th>
<th>No. of Patients</th>
<th>Survivors</th>
<th>Tracheotomy</th>
<th>Oro-tracheal Tube*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Respiratory insufficiency</td>
<td>9</td>
<td>9</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. Pneumonia</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3. Status asthmaticus</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>4. Emphysema with right heart failure</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>5. Chest injury without severe head trauma</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>6. Head injury ± other traumatic lesions</td>
<td>7</td>
<td>1</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>7. Cerebrovascular accident or cerebral tumor</td>
<td>7</td>
<td>0</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>8. Status epilepticus</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>9. Tetanus</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>10. Other neurological disorders</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>11. Postoperative respiratory or circulatory deficiency</td>
<td>31</td>
<td>11</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>a. Abdominal surgery</td>
<td>15</td>
<td>12</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>b. Pulmonary surgery</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>c. Esophageal and mediastinal surgery</td>
<td>43</td>
<td>31</td>
<td>43</td>
<td>0</td>
</tr>
<tr>
<td>d. Cardiac and vascular surgery</td>
<td>134</td>
<td>81</td>
<td>119</td>
<td>15</td>
</tr>
</tbody>
</table>

* An orotracheal tube is left in comatose patients if the ventilatory insufficiency is likely to be of short duration or if the outcome after emergency resuscitation is deemed hopeless.
whereas IPPV will give a more even distribution of the tidal volume and thus increase $P_aO_2$.

The majority of cases treated in a respirator after cardiac surgical procedures (table 1, 11d) have had acquired mitral or aortic valvular lesions or a combination of both or gross pulmonary hypertension due to intracardiac shunts. Among the deaths there were five cases with total prosthesis of the mitral valve and two of the aortic valve.

The main objection to the use of IPPV in cardiac patients would seem to be the possible reduction of the cardiac output owing to raised intrathoracic pressure. However, the favorable effect on the circulation of the better oxygenation of the blood, more than makes up for a slight increase in mean intrathoracic pressure.

A good example of how well IPPV is tolerated in circulatory insufficiency secondary to respiratory insufficiency, was a 48 year old man with emphysema and right heart failure (table 1, 4). In connection with an airway infection he developed peripheral edema, pleural and abdominal effusions in spite of oxygen therapy, digitalization and diuretic drugs. Just prior to tracheotomy and respirator treatment, his $P_aO_2$ on breathing air was 61 mm. of mercury, $Paco_2$ 48 mm. of mercury, pH 7.33 and standard bicarbonate 22.6 mEq. Administration of 50 per cent O$_2$ in the inspired atmosphere increased the $P_aO_2$ to 81 mm. of mercury, but this increase reduced the ventilation so that the $Paco_2$ rose to 52 mm. of mercury. He synchronized well with the respirator. The respiration was completely controlled at a $Paco_2$ of 38 mm. of mercury. He became dehydrated rapidly with a decrease in body weight from 63.5 to 54.2 kg, in nine days in spite of increased food intake. The respirator was then used intermittently and after 18 days the tracheotomy tube was removed. On breathing air he had an $Paco_2$ of 76 mm. of mercury and $Paco_2$ of 44 mm. of mercury.

In conclusion, better results will often be obtained if the respirator is not used as a "desperator" in manifest respiratory and circulatory insufficiency. This "prophylactic" use of tracheotomy and IPPV must, however, be limited to patients, in whom respiratory or
circulatory insufficiency can be predicted following only slight extra loading of respiratory function. Further, the risks of tracheostomy and IPPV per se must be reduced to a minimum. These risks are very slight in comparison with the risks of not actively supporting ventilation in patients with respiratory deficiency.

The change in the PaCO₂ during voluntary hyperventilation as a preoperative test 52 of lung function would perhaps outline the absolute indications for preventive postoperative respirator treatment. Patients without ability to decrease the PaCO₂ during slight voluntary hyperventilation (15–20 liters/minute) have poor respiratory reserve, which will be exhausted by any increased demands on CO₂ elimination from fever, increased respiratory work or metabolic acidosis, which are apt to occur in the postoperative period.

Tracheostomy and Post-tracheostomy Care

Before tracheotomy is performed, an endotracheal tube is always inserted. By this means operative complications such as mediastinal emphysema and pneumothorax, which may occur in cases with a preoperatively obstructed airway, are avoided. 54 We prefer a transverse skin incision. In the trachea a Y-shaped incision is made as high as possible, preferably through the second, third, and sometimes also the fourth rings. 18 Thus a flap, 4 to 5 mm. wide in adults, is made from the tracheal wall. The top of this flap, which has its base inferiorly, is fixed to the lower border of the skin wound by a cutgut suture. This flap prevents the cannula dislocating in front of the trachea and facilitates its replacement in the first postoperative days. Healing of the tracheostomy after decannulation has not been complicated by this technique.

At the present, we use a rubber-cuffed double silver cannula, the inner tube having an extension, of uniform size, 51, 55 which facilitates connection to the respirator 46 (fig. 2). The largest possible cannula should be used. With this type of cannula pressure necrosis has not been observed in any of our patients.

![Fig. 3. Tracheostomized patient with artificial nose. Engström respirator. On the trolley is equipment for tracheal suction and another type of a nonexpandable, flexible rubber tube (solid corrugations) for connecting the patient to the respirator.](image-url)
even if we do not deflate the cuffs at regular intervals. The cuff is inflated just enough to prevent air leakage, and the tube replaced every other day. One patient with complete respiratory paralysis from poliomyelitis was ventilated with an Engström respirator via such a rubber-cuffed double silver cannula for six years without tracheal complications. He finally died from renal calculi due to the prolonged immobilization.

For these reasons the fears of prolonged use of cuffed tracheostomy tubes, which led to the use of uncuffed tubes with a high stroke-volume respirator, seem to be unwarranted. In addition to effectively preventing aspiration, the cuffed tracheostomy tube always makes it possible to deliver a predetermined respiratory minute volume to the patient. Any leak in the respirator or its connection to the patient can be rapidly detected by comparing the preset inspiratory volume with the measured expiratory volume.

An aneroid manometer in the system reveals variations in lung-thorax compliance and airway resistance. Increase in pressure calls for checking of the airway, and in most instances means stagnation of secretions. Sucking out the airways is only done when indicated. A routine introduction of suction catheters at regular intervals will decrease the ciliary activity in the trachea even if the most rigid aseptic technique is maintained.

The most important measure to minimize complications after tracheostomy is to increase the moisture content of the inspired air. The physiological functions of the nose in warming and saturating the inspired air with water vapor must be taken over by artificial means. With the patient on IPPV, this is done by having an efficient humidifier in the respirator. When the patient breathes on his own with an open tracheostomy tube, we have found so-called internal methods for humidification using the heat-and-moisture exchange principle to be most satisfactory. The exchanger often called "the artificial nose," fits into the connection piece of the inner tracheostomy tube and is made in four sizes for different ages (Figs. 2 and 3).

With meticulous technique during tracheostomy and especially with good post-tracheostomy care, the risk of performing this operation is negligible compared with the risk of not doing so in patients in need of respiratory support. This is so even in patients with bronchopneumonia. In chronic pulmonary disease we have performed repeated tracheotomies and IPPV to tide the patients over episodes of acute respiratory insufficiency precipitated by pulmonary infection. In none of these have we so far encountered post-tracheostomy airway complications.

Summary

On the basis of experience from a teaching hospital, the indications for respirator treatment are discussed to point out that the need for this therapy is greater than generally realized. Attention has especially been drawn to indications for "prophylactic" respirator treatment in the early postoperative period in patients with small respiratory reserve.

The variety of disease, which may be complicated by respiratory insufficiency, is wide and because of this, respirator treatment may be scattered over a large hospital. Such decentralization is undesirable as insufficient experience is gained by doctors and nurses, whose main duties are not concentrated on this kind of therapy. Because of the specialized care and attention required by patients in respirators, this kind of treatment should be concentrated in special units. A plea is therefore made for the creation of "intensive care units" with facilities for respirator treatment in every hospital where poor risk patients are treated and major operations performed. The advantage of such an organization is better care of the patient because of improved skill of the nursing staff.

In the respiratory care unit, the anesthesiologist should have a central position because of his expert knowledge of resuscitative measures. It is, however, important that all other specialists cooperate in order to diagnose and treat the underlying disease process. An "intensive care-respiratory care unit" is the ideal place for team work, where all members of the team direct their expert knowledge towards tiding the critically ill patient over a life-threatening situation.

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