

The Emergency Treatment of Acute Respiratory Failure

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A RESPIRATORY emergency is the state when the interference with gaseous exchange in the lungs endangers life. An abnormality of ventilation is the commonest factor which alters the amount of oxygen and carbon dioxide in blood.

The concept of an acute respiratory emergency has long been obvious in the gross asphyxia which occurs in obstruction of the airway or paralysis of the muscles of respiration. Here sudden cessation of ventilation causes death from anoxia within a few minutes although the arterial blood CO_2 tension is only slightly elevated.

When hypoventilation develops gradually, the meager oxygen stores in the body may be supplemented by the inadequate ventilation just sufficient to maintain life. This allows carbon dioxide to accumulate in the tissues producing a high arterial CO_2 blood tension. The combined effects of anoxia and CO_2 excess give rise to the clinical picture of respiratory insufficiency.¹

Previously, these symptoms were regarded as cardiovascular rather than respiratory or metabolic in origin. This state can occur in many conditions and the treatment is the same regardless of the diagnosis of the original disease.

Early recognition of respiratory inadequacy with restoration of adequate pulmonary ventilation before irreversible changes have occurred in the central nervous system has greatly reduced morbidity and mortality.

The Causes of Ventilatory Inadequacy²

These may be classified as follows:

Depression of the Respiratory Center. This can be produced by: (1) narcotic and sedative drugs, (2) anesthetics, poisons and insecticides,

(3) trauma as in head injuries and cerebral pathologic changes, (4) asphyxia, and (5) electrocution.

Breakdown in the Efferent Nerve Pathway. This can be produced by changes: (1) at the neuromuscular junction, occurring in myasthenia gravis and following the administration of relaxants in anesthesia and in treatment, (2) in the peripheral nerves, as in polyneuritis, and (3) in the spinal cord, as in anterior poliomyelitis and multiple sclerosis.

Damage to the Effector Mechanism. The action of the thorax as a bellows can be impaired by: (1) mechanical factors, such as injuries to the chest wall (either by accident or operation); obstruction of the airway by edema, foreign body or aspiration; gross obesity; kyphoscoliosis and ankylosing spondylitis, and (2) pathological factors, bronchitis, emphysema, asthma and pulmonary infections; scleroderma, pleural effusion, pneumoconiosis, respiratory distress syndrome in infants, and drowning.

The Clinical Picture in Respiratory Insufficiency³

Dyspnea with increased respiratory effort is due to the central effects of retained CO_2 and the lowered oxygen tension in blood together with obstruction of the airway by secretions. Mental confusion is due to the combined effects of anoxia and hypercarbia.

In the early stages the patient is anxious, restless and irritable; the skin of extremities is warm and the vessels dilated. The pulse is full and bounding and the blood pressure only slightly raised. Later coma ensues, which is followed by hypotension and failure of the vital functions of respiration and circulation.⁴ The degree of hypoventilation is usually obvious from the rapid shallow respiratory efforts, the moderate cyanosis and the

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accumulation of secretions in the respiratory tract.

The administration of oxygen without assisted ventilation will alleviate the cyanosis, but it may abolish all respiratory movement by removing the hypoxic stimulus to the respiratory center which has become insensitive to the high carbon dioxide level in the blood. Upon correction of the ventilatory inadequacy, venous congestion subsides, the blood pressure and pulse stabilize and the patient slowly recovers consciousness and lucidity.

The Assessment of Pulmonary Ventilation

In children, restlessness and inability to cry is often a sign of respiratory insufficiency. In adults, the force and quality of the cough reflex is a reliable guide to the function of the bellows action of the thorax and the patency of the airway.

When the volume of each breath is reduced by more than one half of normal, the gaseous exchange in the alveoli is inadequate. If the vital capacity drops to 30 per cent of normal, ventilatory support is necessary.

The most useful physiological measurements of ventilation are those which give some index of the volume of air that can be moved per unit of time.

A Wright peak expiratory flowmeter will measure the maximum velocity of expiration. In normal adults the reading should be approximately 500 liters per minute. Below 100 liters per minute indicates ventilatory inadequacy.

The Wright respirometer⁵ will give a measure of the expired air minute volume which can be compared with the table of normal values on Radford's nomogram.⁶ This instrument has vanes which are caused to rotate by the stream of gas; the number of rotations is proportional to the volume of air passed. It will respond to gas flow in only one direction, though gas can pass easily in either direction. This enables it to be placed directly in the patient's airway without the interposition of valves to secure unidirectional flow, which all other volume meters require. During ventilatory therapy, the expired air minute volume is a valuable index of the accumulation of obstructing pulmonary secretions and of the need for chest physiotherapy and an artificial cough.

The rebreathing equilibration technique of Campbell and Howell is a practical clinical test for the estimation of the arterial and mixed venous P_{CO_2} .⁷ It is not influenced by the compliance of the lungs as may interfere with end-tidal air studies, causes minimal disturbance to the patient, and is within the capabilities of house staff who can perform the analyses themselves in the ward with a modified Haldane gas analysis apparatus. A reliable estimate of the alveolar CO_2 can be obtained within five minutes. This is the method we have used routinely to assess the adequacy of ventilation during respiratory treatment and in complicated metabolic disturbances.

A more accurate guide to pulmonary ventilation is the estimation of the arterial blood carbon dioxide tension by the direct methods of Astrup or Severinghaus using CO_2 electrodes.⁸ For this, adjacent laboratory facilities and skilled personnel are necessary.

An indirect method of measuring the P_{CO_2} is from the pH of an arterial blood sample and the total CO_2 content utilizing the Hendersson-Hasselbalch equation to calculate the result.⁹

Emergency Ventilatory Procedures

The guiding principle is to ventilate the lungs sufficiently to maintain the arterial P_{CO_2} between 35–45 mm. of mercury and the arterial O_2 saturation at 98 per cent with the least disturbance possible to the cardiac output and the systemic blood pressure. The upper airway which extends from the lips to the glottis is the keystone to successful artificial ventilation.¹⁰ Maximal backward tilting of the head is the important maneuver to establish and maintain a clear airway under field conditions. Obstruction of the airway by the lips, tongue, mucous secretions and foreign debris, which is usually regurgitated gastric contents, can be corrected by posture and suction.

Manual methods of artificial respiration, of which the best are the Holger-Nielsen and the Brosch modification of the Sylvester method are unreliable due to the tendency for the tongue to obstruct the airway.¹¹ In the "push-pull" methods the hands are used to alter the volume of the thorax and produce

gaseous exchange. Often it is not possible to do this and maintain a clear airway under emergency conditions.

It has been shown that positive pressure inflation with expired air methods give more effective gaseous exchange than the manual methods when a clear airway has been secured, especially in the presence of lung disease, such as decreased lung compliance and venous shunts.¹²

In an emergency, speed and ability to act independently of equipment, can decide between life and death. Mouth-to-mouth or mouth-to-nose expired air ventilation will provide gaseous exchange and prevent irreversible damage to the central nervous system until equipment can be procured to render the maintenance of adequate ventilation less tiring.

An easily portable respiratory emergency kit contains a foot-operated suction, a self-expanding bag of the Ambu type for fresh air insufflation, a laryngoscope and a selection of endotracheal tubes. Relaxant drugs, vasopressors, hypnotic and analgesic drugs are included to ensure adequate management of any condition producing respiratory insufficiency (fig. 1).

Physiological Principles in Emergency Artificial Respiration¹³

The presence of fluid in the tracheobronchial tree necessitates a greater inflation pressure to ensure adequate ventilation than applies in normal lungs. It is thought that the increased elastic resistance of the lungs (decreased compliance) is due to an alteration in surface tension effects by the physical properties of water which lead to scattered areas of atelectases and over-ventilated alveoli. This results in venous shunts in the lungs and ventilation with 100 per cent oxygen may be necessary to raise the arterial oxygen saturation to normal values. It is not possible to reinflate some of the collapsed alveoli without producing an unduly high pressure in the airway and lungs. To avoid the risk of pneumothorax and to overcome the anoxic effects of large venous shunts, a pressure of less than 30 mm. of mercury should be used for inflation of the lungs. The Ambu bag unit supplies a maximal inflation pressure of less than 30 mm. of mercury in the ventilation of normal lungs.

This pressure is about half that produced by the human bellows in expired air ventilation. Most of this force is used to overcome the resistance of the lungs and the thoracic cage.

A mean airway pressure between 6-10 cm. of water may produce a fall in the cardiac output by interfering with the venous return to the right side of the heart. This effect can be minimized if the positive pressure is only applied for one second and the rate of ventilation is limited to 8-12 per minute.

Ventilation of the lungs with 100 per cent oxygen at atmospheric pressure is free from danger over short periods but should not be permitted to extend over 24 hours. Usually emergency artificial respiration must be maintained for at least 30 minutes. When the circulation is stabilized and prolonged ventilation is necessary, the patient can be transferred to a respiratory unit for further management. The transportation should be supervised by an anesthesiologist with the airway secured by endotracheal intubation and obstructing secretions controlled by suction and by the production of an artificial cough. The Ambu Bag Unit is a convenient and efficient method of ventilation during transport and also for the production of an artificial cough.

Subsequent Ventilatory Management

TRACHEOSTOMY

This is necessary when intermittent positive pressure respiration (IPPR) is required for longer than 24 hours. Endotracheal tubes are irritant to the upper airway, produce discomfort and increase oropharyngeal secretions in a conscious patient. Loss of the glottic reflex with inability to swallow and obstruction of the airway are the principal indications for tracheostomy. The advantages of a tracheostomy are: The tracheobronchial tree is isolated; removal of pulmonary and pharyngeal secretions is facilitated; the respiratory dead space is reduced by one third; the resistance to respiratory effort is lessened; and nursing, physiotherapy, roentgenographic procedures and intermittent positive pressure therapy are simplified. The disadvantages associated with tracheostomy can largely be overcome by good management. When the nose and pharynx are bypassed their protective function of arresting the entrance of bacteria and dust into

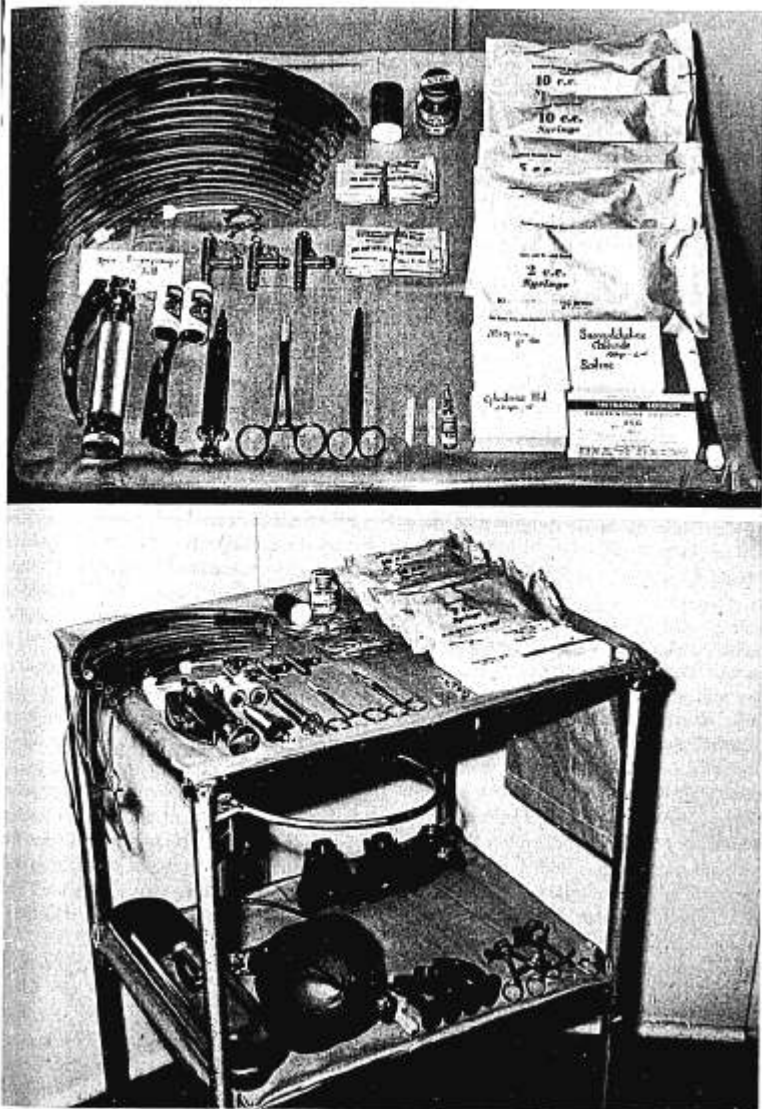


FIG. 1. Two views of the respiratory emergency trolley, which carries an Ambu Bag, laryngoscope with adult and children's blades, spare batteries and bulbs. There is a selection of endotracheal tubes, sterile syringes and needles with vasopressor, relaxant, hypnotic and analgesic drugs to ensure adequate management of a respiratory emergency. The sterile suction catheters are in the container beside the ventilating bag.

the lungs is lost.¹⁴ The tracheostomy tube has an irritant effect increasing the tracheobronchial secretions and interfering with the ciliary streams which line the respiratory tract and have an essential cleansing action. Following tracheostomy it is necessary to warm and humidify respired air or gases to 100 per cent saturation with water vapor to preserve the activity of the ciliary streams, to clear invading bacteria and prevent pulmonary infection. A suitable humidifier for this purpose has been described by Spalding.¹⁵ When a tracheostomy is present the patient is dependent on suction for the removal of pulmonary secretions. This is most effectively performed by the production of an "artificial cough" which also simulates a deep breath and helps to ventilate nonperfused alveoli. In this maneuver the over-inflation of the lungs dilates the bronchi, forces secretions out of the alveoli and allows air to get in behind the obstruction. During expiration the loosened secretions are dislodged into the larger bronchi from which they can be aspirated.

It must be remembered that suction catheters themselves can introduce pathogenic organisms. Strict asepsis and avoidance of trauma to the mucosa during aspiration is essential. Care of the tracheobronchial tree is best managed by experienced physicians and nurses in an air-conditioned treatment area.

Technical Features in Tracheostomy. The procedure is performed under general anesthesia with endotracheal intubation and adequate pulmonary ventilation. The opening into the trachea is made at the level of the second and third tracheal rings and should be of sufficient size to accommodate a right-angled rubber tracheostomy tube of the James or Morant-Baker type. The largest tube which will fit easily into the trachea is chosen. In adult males a no. 42 French catheter to which a detachable latex cuff is attached to seal off the trachea, is suitable. In this site the tube lies comfortably without distortion of the trachea. A large tube facilitates aspiration of secretions and prolongs the life of the detachable cuffs. The inflation and deflation of the cuff is performed every two hours when the posture is

altered and the patient is in a slightly head-down position to reduce pressure effects on the tracheal mucosa and to prevent the entrance of oropharyngeal secretions. With adequate humidification the tube can be left in place for several days. During the first two days if the tube has to be removed (*e.g.*, a burst cuff), facilities for orotracheal intubation must be available due to the risk of tracheal collapse. After 24-48 hours granulation tissue forms a tract eliminating the difficulty of changing the tube.

To keep the tracheobronchial secretions fluid and easily removable and to produce a diuresis of at least 1,500 ml. per day, the patient requires adequate hydration of up to 5 liters of fluid per day.

Culture and antibiotic sensitivity tests of the tracheobronchial aspirate should be performed regularly at least twice weekly to assist in combating infection.

When a cuffed tracheostomy tube has been *in situ* for several days the larynx loses its normal protective reflex of closing in response to anything but air. Before final removal of the tracheostomy tube a fenestrated uncuffed tube is inserted for one or two days. This is not removed until the patient can phonate, swallow and sleep undisturbed with it completely occluded. Following decannulation the tracheostomy stoma closes rapidly within two or three days.

Metal, plastic or nylon tracheostomy tubes are less irritant to the tissues than the rubber types. They have the disadvantage that the detachable latex cuffs are more liable to slip into the trachea when they are inflated and produce obstruction of the airway which can be fatal.

In children under 5 years, overgrowth of granulation tissue in the trachea can follow tracheostomy decannulation. The hazard of tracheal stenosis can be reduced by using correctly fitting tracheostomy tubes, careful inflation and regular deflation of the cuff and avoiding distortion of the trachea by unsupported respiratory equipment attached to the tracheostomy tube.

PRINCIPLES IN THE USE OF SUCTION

The method of suctioning is important to avoid atelectases and disturbances to the circulation from a greatly increased intrapulmonary negative pressure at the height of inspiration. The change in the negative pressure within the lungs is related to the ratio of the diameter of the suction catheter to that of the inside diameter of the tracheostomy tube or the trachea.¹⁶ A high negative pressure in the lungs can be avoided by using a suction catheter which has an outside diameter less than half the inside diameter of the airway.

Aspiration of oropharyngeal and tracheo-bronchial secretions are effected by separate apparatus; the mouth, preferably with a metal suction piece, and the trachea, by sterile pliable plastic catheters open at the end with an aperture on each side 1 cm. and 1.5 cm. from the tip. The catheter should be passed as far down the tracheobronchial tree as possible and suction applied during withdrawal during which the catheter is gently rotated. The catheter should not be agitated or dabbled and should always be discarded after use. Only a sterile catheter should be introduced into the tracheobronchial tree.

Suctioning should always be performed before and after changes of posture, chest physiotherapy and the production of an artificial cough. Strict asepsis with the wearing of a mask, gown and the donning of sterile gloves should be practised. Aspiration is best performed intermittently, preferably after a maximal inflation of the lungs and should be restricted in duration to less than 45 seconds.

Clamping the catheter before introduction into the trachea allows a maximal build up of negative pressure which is transferred to the airway on removal of the clamp. An opening at the proximal end of the catheter, which can be occluded with the finger when suction is required, is less traumatic and is effective. A safe negative pressure range for tracheal suction is 5-7 inches of mercury. It is unwise to exceed 10 inches of mercury.

It is an advantage if the catheters are of transparent plastic material to allow inspection of material aspirated and its passage up the catheter.

NURSING AND MEDICAL CARE

Experienced nursing personnel are essential to maintain a clear airway and to manage the complicated treatment. They are the most important members of the team. Familiarity with the specialized equipment, ability to recognize an emergency early and to handle it must be within their capabilities. They must avoid accidents, which can be fatal. The ideal location for this management is the acute treatment area of the hospital, which includes the operating suite, recovery room and the intensive care area. In this region there is usually air conditioning with good ventilation and the general structure, the equipment, the facilities and the daily duties of personnel are similar to that required for care of respiratory emergencies. When the management of ventilatory inadequacy is carried out in the ward in which it occurs there is often frustration and chaos due to frequent changes in the medical and nursing personnel and the lack of continuity in treatment. All of this is aggravated by the divided responsibility inseparable from such an arrangement.

PROLONGED ARTIFICIAL RESPIRATION

When the management of ventilatory failure is likely to extend over several hours, the treatment is carried out in a respiratory unit with the aid of automatic ventilators. Pressure constant machines permit regular monitoring of the expired air minute volume. This indicates the need for chest physiotherapy and the aspiration of accumulated pulmonary secretions to prevent hypoventilation and the development of atelectases.¹⁷

The Radcliffe positive pressure respiration pump with cam operated valves is our choice for prolonged treatment in apneic patients. It is simple to operate, has a built-in humidifier and ventilation meter and will operate for long periods with minimal maintenance.

The Bird Mark VII respirator is favored for triggering assisted respiration in the management of ventilatory insufficiency in asthma and pulmonary disease. A humidifier of the Marshall-Spalding type has been introduced between the ventilator and the rebreathing head to humidify the respiratory tract.

In the conduct of prolonged artificial respiration a slow respiratory rate of 8-10 per minute with a tidal volume of 800-1,000 ml. is preferred to compensate for the increase in the physiological dead space and to reduce the effect of raised intrathoracic pressure on the circulation.

The Management in Specific Conditions

POLIOMYELITIS AND POLYNEURITIS

In spinal poliomyelitis and polyneuritis without bulbar involvement or obstruction of the airway by secretions a cabinet respirator is useful to rest the muscles of respiration, relieve anxiety and provide adequate alveolar ventilation before respiratory failure develops.¹⁸ This is indicated when the vital capacity drops to 30 per cent of the predicted normal. Routine daily measurement of the peak expiratory flow rate, the expired minute volume and tidal volume will warn of progressive involvement of the respiratory muscles.

The cabinet respirator avoids a tracheostomy, allows the patient to converse and prevents the gradual onset of anoxia and carbon dioxide accumulation leading to a respiratory emergency. Early uncomplicated recoveries of respiratory function have been procured by this use of a tank respirator. They are bulky and awkward for nursing, clinical investigation and radiological procedures due to the inaccessibility of the patient. This is a minor problem when it is mainly used to ensure adequate rest and sleep at night and the patient can be removed for progressively increasing intervals during the day.

In the presence of excessive pulmonary secretions and bulbar involvement, intermittent positive pressure machines are preferred for long term use and for the control of pulmonary complications.

TETANUS, STATUS EPILEPTICUS AND CONVULSIVE STATES

In these conditions which have a different etiology the spasms and their control by sedation can lead to exhaustion and the development of respiratory failure.¹⁹ Relaxant therapy and IPPR treatment is necessary when the spasms cannot be controlled by sedation without inducing respiratory insufficiency. This is

indicated by the routine daily assessment of the pulmonary ventilation.

The relaxant drugs convert the spastic patient into a flaccid one. This allows a reduction in the dosage of depressant required to produce unconsciousness and permits adequate control of the blood gases by IPPR. The caloric and oxygen requirements are also reduced when the patients cannot move and do not breathe for themselves. These patients can be the most complicated to manage. Tracheotomy is performed under relaxant and endotracheal anesthesia with adequate pulmonary ventilation. In the first few days when the dose of relaxant and the fluid balance is being adjusted, a spasm may occur in spite of curarization with the grave risk of gastric, regurgitation and rupture or displacement of the cuffed tracheal tube leading to obstruction of the airway. *d*-Tubocurarine chloride is my relaxant of choice. It has few side effects and the longest duration of action. The aim is to produce complete apnea which may have to be continued for three or four weeks.

After 3-10 days the dose of relaxant can be reduced and the course of the disease is judged by the severity and duration of returning muscle spasms. A rise in the expired air minute volume, which should be measured every one-half hour during IPPR, indicates the patient is breathing with the respirator. In the absence of recurrence of convulsions, a trial off the respirator should be planned. This can be accomplished by discontinuing the relaxant and adjusting the positive pressure on the respirator to provide a ventilator within normal limits for the body surface area of the patient. When there is evidence of return of consciousness and voluntary movement, the anesthesiologist can take over from the machine and maintain analgesia and CO₂ equilibrium with 50 per cent nitrous oxide and oxygen from an anesthetic machine to allow gradual return of consciousness and spontaneous respiration. Any residual curarization can then be corrected without the risk of a major spasm. The tracheostomy tube is removed when the respiratory function is adequate on routine measurement.

In neonates and infants the difficulties in management are greatly increased by the

anatomical and physiological limitations at this age. The prevention of complications, especially bronchopneumonia, requires scrupulous attention to detail and treatment by an experienced team.²⁰ When a tracheostomy is necessary it is better to use a vertical slit through the second and third tracheal rings rather than cut a window. The type of opening into the trachea determines the ease with which the tube can be permanently removed. In the management of IPPR in this group, constipation and paralytic ileus are common in the initial stages and weaning from the respirator is difficult. The best results are obtained when this is accomplished within two to three weeks. Our experience with the neonatal form of tetanus has been sporadic and unsuccessful.

There is no drug specifically effective in reducing the death rate in tetanus. Phenothiazine and relaxant drugs will reduce the spasms, but the important factor in reducing the mortality is the supportive care during the complicated treatment. Team work between the anesthesiologist and the physician is essential. All decisions must be made by the most experienced members of the team who supervise their execution.

CRUSH INJURIES OF THE CHEST AND MULTIPLE TRAUMA

The increasing frequency of this trauma is related to the mechanization of modern living and especially to automobile accidents. There are often multiple injuries. Many of these victims die untreated, from the effects of anoxia and CO₂ accumulation soon after admission. The treatment of respiratory insufficiency by applying the principles of a clear airway, adequate gaseous exchange and the correction of air leak and paradox, must receive priority followed by restoration of circulatory function. The diagnosis and treatment of neurological dysfunction can wait for the response to this initial emergency therapy. A workable scheme for the immediate assessment in extensive trauma is as follows:²¹

Thorax: (1) the level of consciousness and ability to produce an effective cough, (2) inspection for dyspnea, labored respiratory efforts and venous congestion, (3) air leak into the mediastinum or into the pleural cavity,

and (4) palpation for instability of the thoracic cage.

Circulation: (1) venous engorgement of the face and neck with hypotension is due to tension pneumothorax, and (2) peripheral circulatory failure requires blood replacement.

Neurological: (1) depth of coma, and (2) trauma to the skull and spinal cord.

Abdominal: trauma to liver, spleen or bladder.

Skeleton: multiple fractures requiring blood replacement.

The clinical picture of respiratory failure may be due to paradoxical respiration from instability of the thorax, contusions in the lungs by fractured ribs, collapse of the lungs from pneumothorax, hemothorax, obstruction of the airway or the reflex response to painful stimuli. Pain relieving drugs administered by first aid attendants can be potent depressants of respiration. On admission many victims exhibit signs of gross neurological dysfunction and circulatory failure which could be due to extensive brain trauma or hemorrhage. In all cases immediate correction of the abnormality in the blood gases is essential when there is ventilatory inadequacy. This can be confirmed by measurement.

The emergency treatment consists of essential measures to ensure survival. This is carried out by specialized personnel who are alerted while the victim is being transported to the hospital. If the patient is restless and disorientated he must be anesthetized. The airway is cleared and tracheobronchial toilet is carried out through an endotracheal tube. At this stage, high intrapulmonary pressures should be avoided when administering oxygen to avoid the risk of producing a tension pneumothorax. The retention of some spontaneous respiration is important until pleural drainage has been established in the presence of an air leak. The treatment of circulatory failure by the infusion of fresh dried plasma and blood when it is available, should be started as soon as the patient has quieted and the airway secured. Pleural drainage can then be established on the injured side. If in doubt, both pleural cavities should be drained through the second intercostal space anteriorly into under-water seal bottles. Controlled pulmonary ventilation with oxygen can then be

practiced to abolish the paradox and restore the blood gases to normality. Relaxants and/or pain relieving drugs using hyperventilation with oxygen from an anesthetic machine or an Ambu Bag will enable this control during which a careful record should be maintained of the blood pressure and the pulse rate. The establishment of adequate pulmonary ventilation is often followed by a great improvement in the circulation and in the level of consciousness. In the absence of continuing hemorrhage, large transfusions are not required to restore the circulation.

Analgesic drugs are needed to relieve pain and restlessness coincident with the recovery of consciousness. When the vital functions of respiration and circulation are under control, further examination and investigation is possible. Roentgenogram of the chest in the upright position will indicate the extent of the damage to the thoracic cage and the presence of air, blood or abdominal viscera in the chest. Roentgenogram of the skull and vertebral column with examination of the central nervous system for focal damage is done when this is indicated. Brain damage from depressed skull fractures and collections of blood under or outside the dura require early evacuation to avoid irreversible cerebral changes. Fractured limbs should be examined and splinted last.

During these investigations emergency pulmonary ventilation with oxygen should be continued while the blood pressure, pulse and general circulatory state is closely monitored. If the circulation is unstable or the initial improvement is not maintained, the source of bleeding may be in the liver or spleen in the absence of hemorrhage from inside the chest as shown by the water seal drainage bottles. To exclude intra-abdominal hemorrhage if suspected under these conditions it is wiser to inspect the peritoneal cavity through a small laparotomy incision rather than rely on a clinical diagnosis. When there is excessive drainage of blood or air from the thorax an immediate thoracotomy is required to close the air leak or control the bleeding. Surgical emphysema rarely needs treatment when the pleural cavities are drained. Following the control of hemorrhage and air leak respiratory management may be necessary for days.

A high tracheostomy should be performed for the application of IPPR if this is required and the maintenance of a clear airway and tracheobronchial toilet.

If paradoxical breathing persists the inadequate respiratory efforts can be controlled by relaxants or by hyperventilation and depressant analgesic drugs (e.g., morphine) which will induce amnesia and relieve pain.²² Alternatively, a patient-triggered respirator can be used to augment ventilation. This subsequent treatment is best carried out in a respiratory unit with a single person in charge who has full responsibility for the respiratory management.

HEAD INJURIES

On the admission of a patient suffering from a head injury, the two principal problems are maintenance of a clear airway and an adequate circulation. When unconsciousness is due to brain damage, even partial obstruction to respiration is more disastrous than in other diseases. As a result of direct trauma there is already a tendency to cerebral edema. If anoxia and hypercarbia, together with a rise in the venous pressure is added, an increase in the brain bulk is to be expected. The passage of an endotracheal tube will overcome the immediate emergency and allow a tracheostomy to be performed under favorable conditions. It is unwise to leave the endotracheal tube in place longer than necessary owing to the increase in oropharyngeal secretions and the rise of increased respiratory efforts when consciousness begins to return. The principal advantages of a tracheostomy with adequate humidification in the treatment of a head injury is the trachea is isolated, tracheobronchial secretions can be controlled and the normal resistance to breathing is reduced. The reduction in the dead space may be sufficient to restore normal gaseous exchange. This can be measured by the rebreathing bag equilibrium test.

In a severe head injury apnea due to cerebral compression always means irreversible brain damage. If immediate surgical relief the pressure is not possible it is wise to use IPPR.²³ In these cases it only postpones the inevitable and prolongs life for some weeks. Intravenous hypertonic urea (Urevert) v

also reduce the intracranial pressure. Its use is contraindicated in acute head injuries except as an immediate preoperative measure due to the risk of increased hemorrhage.²⁴

BARBITURATE INTOXICATIONS

The mortality from barbiturate poisoning is very low using supportive therapy alone. When there is depression of the pharyngeal and laryngeal reflexes an endotracheal tube will maintain a clear airway. Apnea can be treated by IPPR via the endotracheal tube using an automatic respirator, while to prevent hypostatic congestion of the lungs the patient should be turned from side to side every two hours. The circulation can be supported by vasopressor drugs, such as, ephedrine, methyl amphetamine sulphate or metaraminol (Aramine). An infusion of 5 per cent glucose providing 3 liters of fluid per day should be used to promote a diuresis and give an adequate fluid balance. In irrational or unconscious patients the airway should be protected by endotracheal intubation before gastric lavage. These patients invariably recover adequate pulmonary ventilation within 8–12 hours and consciousness within 24–48 hours in the absence of complications. Tracheostomy should be performed only when the endotracheal tube has to be retained longer than two days. In severe intoxications the duration of coma can be shortened by hemodialyses.²⁵ This is indicated when there is difficulty in maintaining systolic blood pressure of 80 mm. of mercury to prevent renal tubular necrosis.

ACUTE LARYNGEAL OBSTRUCTION AND LARYNGOTRACHEOBRONCHITIS

Both infections are of sudden onset and are characterized by dyspnea, labored respiratory efforts and inability to produce an effective cough. On admission the children are confused, restless, anxious and irritable from the effects of anoxia and hypercarbia due to the obstructed airway. The pharyngeal and laryngeal reflexes are depressed with pooling of secretions in the pharynx and trachea. When the assessment of the pulmonary ventilation and the clinical signs indicate the need for active intervention, inspection of the pharynx and larynx should be carried out by direct laryngoscopy without anesthesia. This can be

performed with the aid of an assistant to hold the child in position. It is atraumatic when carried out by an experienced bronchologist or anesthetist using an appropriately sized laryngoscope blade. Following aspiration of the pharyngeal secretions intubation of the trachea with a nylon tube a size smaller than normal is not difficult. When the airway has been restored and the tracheobronchial accumulations removed by an "artificial cough" there is usually a dramatic, rapid recovery of consciousness and muscle tone. If tracheostomy is necessary due to the presence of inflammatory glottic edema, inhalation general anaesthesia should be induced via the tube using halothane or cyclopropane without premedication. We have observed no embarrassment from this technique. All patients between 3 and 10 years have denied recollection of the events associated with the operation. Many deny memory of their admission to hospital. Tracheostomy can thus be performed under ideal conditions devoid of troublesome bleeding, increasing anoxia and hypercarbia in a struggling patient. Patients with tracheobronchitis without laryngeal edema are spared the discomfort of a tracheostomy and have an uneventful recovery under antibiotic therapy in a steam tent.

Prior to the adoption of this regime four of our patients between 2 and 4 years died during the performance of tracheostomy under local analgesia.

CARBON DIOXIDE NARCOSIS AND ANOXIA IN PULMONARY DISEASE

In pulmonary disease there is interference with the mechanics of breathing and abnormalities of the pulmonary circulation. When the pulmonary ventilation is further depressed by sedatives or superimposed infection, respiratory failure is likely to occur. The effects of hypoxia and carbon dioxide excess on the cardiovascular system can produce severe pulmonary hypertension and right ventricular congestive failure. Cerebral vasodilatation will occur with a rise of intracranial pressure producing coma.²⁶

It is essential to provide effective oxygenation of the arterial blood to avoid death due to cerebral depression and heart failure. The administration of oxygen in 20 to 30 per cent

concentrations in the inspired air combined with intravenous nikethamide in doses of 4-8 ml. every four hours has been tried to provide adequate gaseous exchange. This often has been ineffective in the presence of coma. In partially conscious patients large doses of analeptics produce unpleasant irritation of the skin and intense dyspnea. The increased respiratory efforts raise the demand for oxygen and may precipitate severe cerebral edema in borderline cases.

The most effective emergency therapy is removal of the secretions by endotracheal intubation and the production of an artificial cough followed by administration of oxygen in concentrations up to 30 per cent²⁷ and broad spectrum antibiotics to control infection. Tracheostomy with effective humidification is necessary if a relapse occurs. If this therapy is inadequate, IPPR with 30 per cent oxygen will provide effective ventilation and increase blood oxygen saturation. This will reduce the pulmonary hypertension and the load on the right ventricle. In emphysema, IPPR can be hazardous due to the presence of air trapping which raises the intra-alveolar pressure. The persistently raised intrathoracic pressure impedes venous return and can produce a fatal fall in cardiac output. This hazard to the circulation can be reduced by a slow inflation rate of 8 per minute to allow a prolonged expiratory phase and a lower mean intrathoracic pressure. The important factor bearing on the prognosis is the degree of pulmonary reserve present before the acute episode of respiratory failure. Patients who are chronically dyspneic at rest do badly, those who are active before admission do well.

POSTOPERATIVE RESPIRATORY FAILURE

Failure to breathe following anesthesia and operations may be due to central depression of respiration and peripheral factors associated with the procedures.

Elimination of the bellows action of the thorax can be due to the relaxants, anesthetics, depressant drugs, the effect of the surgical procedure and hyperventilation or hypoventilation of the lungs. In each instance the interference with pulmonary ventilation can often be compensated for if the circulation and pulmonary reserve is adequate.

When there is pre-existing cardiac or respiratory disease the possibility of the physiological upset of operative procedures and prolonged anesthesia producing respiratory failure must be guarded against. This is treated by maintaining an adequate pulmonary ventilation and circulation until the limiting effects of the operation and depressant medication have been resolved.

The diagnosis of the cause of apnea following the use of relaxant drugs has been aided by the use of a nerve stimulator to demonstrate the nature of the myoneural block.²⁸ In many cases of postoperative apnea this device has shown that the relaxant itself was not at fault.

The Facilities for Respiratory Care

These are best provided in a respiratory unit staffed by a medical and nursing team of experts. To serve a population of approximately one million, we have found that space (double that necessary for one ordinary patient) is required for six patients. An open planned area with an elevated nursing station is ideal to ensure constant observation. Adjacent bedroom accommodation is required for a resident doctor who must always be available. A small laboratory for the estimation of pH, P_{CO_2} , and O_2 saturation and for acid-base studies is desirable in this area.

The transportation of patients to the unit should be supervised by an anesthesiologist equipped with a portable suction and a self-inflating bag for pulmonary ventilation via an endotracheal tube.

One person must assume full responsibility for the respiratory management. Specialists in all branches should be available for consultation and the referring physician should be free to maintain an interest in the patient's welfare. The head of the unit and his assistant should be permanent full-time anesthesiologists able to devote all their energies and interest to the immediate care during the critical hours following admission. The supervision of the clinical records and monitoring of the patient during IPPR is important to enable reliable conclusions to be made and to provide a basis for discussion in the conduct of a program of clinical investigation. In our unit, both clinicians retain a close contact with clinical anesthesia by engaging in four anes-

thia operating sessions per week, so organized that one of them is always available in the unit. This allows constant senior expert coverage, relief for off duty and teaching. A general physician is a member of the team on a part-time basis. His duties are to advise on general medical problems, the control of infection and provoke discussions. A surgeon is attached to the team to advise on surgical problems and to perform the tracheotomies and minor surgical procedures required.

We attach junior anesthesiologists to the unit part time over a period of two years during his training to acquire experience of the special methods. He organizes the transportation of respiratory patients and assists in the management during emergency stations. The junior resident staff are responsible for routine blood and biochemical estimations, emergency care in the unit and the completion of *pro formae* on admission and transfer with the full notes and a summary of the treatment.

The purposes of the unit are explained to the patient and relatives by the 'sending' service.

Results of Treatment

This type of treatment is a discipline still being developed which is subject to growing pains. Changes in therapy take time to become established and accepted. With improved liaison and the earlier recognition of ventilatory inadequacy by simple methods of monitoring, the number of requests for assistance has been increasing each year. Most of the cases referred for therapy have had neurorespiratory diseases with deficient ventilation and inability to swallow. These conditions have a good prognosis and are simple to manage by IPPR which allows time for the diagnosis to be made and the treatment of the original disease to be effective. The need for artificial ventilation in paralysis of the muscles of respiration has been obvious for many years. It is not so well known that the maintenance of adequate ventilation in the presence of muscular weakness and incipient exhaustion will avoid a respiratory emergency and promote earlier recovery to full function, by resting the muscles and relieving anxiety. In acute laryngotracheobronchitis sudden obstruction to ventilation has been fatal during

the performance of a tracheostomy under local analgesia. The expedient of first securing an airway by endotracheal intubation and aspiration of the secretions reduces the hazards of this condition. There have been no complications from the adoption of this regime in a small number of cases.

Patients with head injury are often unsalvageable when there is prolonged loss of consciousness due to brain damage by trauma or intracranial hemorrhage. Our neurosurgical service recognizes that in this state IPPR can merely prolong life and death is inevitable if the cerebral compression cannot be immediately relieved by operation. This accounts for the few neurosurgical patients referred for the treatment of ventilatory inadequacy.

Barbiturate and drug intoxications are relatively simple to manage. The only death in our series occurred in a child of 4 years who was admitted moribund following an episode of cardiac arrest during transportation to hospital. She died from the effects of this anoxia after seven days of therapy.

Patients with tetanus can be the most hazardous and complicated to manage. In this disease as in other conditions predisposing to respiratory insufficiency, tracheostomy is not a routine procedure. There must be indications for it due to the increased problems of management and the risk of complications. Infection is common and care in the management of the secretions and humidification is essential to prevent distortion of the trachea and damage to the mucosa by injudicious suction. There have been two cases of tracheal stenosis following tracheostomy in tetanus both of which are now responding to conservative measures after two years. At present, paralysis by relaxant drugs with IPPR offers the best chance of survival in the severe case. Responsibility in the management of severe tetanus cannot be delegated to junior house staff. This was emphasized recently in the deaths of two successive patients with tetanus when this principle was ignored. There have been three cases of neonatal tetanus over a period of four years. Our inexperience in the prolonged management of these cases contributed to their deaths from respiratory failure and bronchopneumonia after 4-10 days.

TABLE 1. Results for 1958-1961

Disease	Treated	Survived	Died
Poliomyelitis	20	19	1
Tetanus	21	17	4
Peripheral neuritis	7	6	1
Barbiturate intoxications	19	18	1
Postoperative respiratory failure	24	17	7
Acute laryngotracheobronchitis	23	19	4
CO ₂ narcosis and pulmonary disease	6	4	2
Status asthmaticus	1	1	0
Status epilepticus	1	1	0
Stove-in chest	1	0	1
Head injuries	9	0	9
Cerebral pathologic changes	4	0	4
Lesion of the cervical cord	1	1	0
Disseminated sclerosis	2	2	0
Lower motor neurone disease (sclerosis of the cord)	1	0	1
Myasthenia gravis	1	1	0
	141	106	35

Serious chest injury is often associated with multiple injuries. The treatment of respiratory distress must be the first step in resuscitation. It is a long drawn out, complicated battle to prevent the death of these patients. Experienced care is necessary round the clock with a constant watch for increasing paradoxical respiration which could have been relatively minor soon after the injury. These patients are the exception to the general rule of two hourly changes of posture with artificial coughing during IPPR. They are placed on an air mattress in the sitting position when this is practicable, since pain and delayed union can result from frequent turning and chest physiotherapy. Many of the milder cases with pulmonary air leak are treated by the surgical service and only require pleural drainage if the pulmonary reserve is inadequate. The elderly are often handicapped by an inadequate cardiorespiratory reserve which militates against recovery especially when there is delay in recognizing the onset of ventilatory inadequacy as occurred in our case.

In pulmonary disease the prognosis depends on the state of the cardiorespiratory reserve before ventilatory inadequacy develops. Status asthmaticus and severe pneumonic infections in the young have responded most dramatically even when the patient was deeply comatose and in right ventricular failure with pulmonary hypertension. In the elderly with chronic dyspnea the outlook is dismal. The number of cases in this series is small. However, we are concerned with a method of treatment which we have used since 1958. It is im-

portant that the results of this treatment be assessed to enable a wider recognition of the emergencies that are worthy of therapy. The full clinical details and the prognosis in each case must be recorded to enable reliable conclusions to be made.

Of the 141 patients treated, 106 survived (table 1). The seven deaths in the postoperative group were made up of five cases following major pulmonary or cardiac surgical procedures. One patient died from severe metabolic derangement following operation for abdominal stab wounds. The other case was admitted with irreversible anoxic damage following a cardiac arrest during an upper abdominal operation.

All the survivors made a complete recovery except six poliomyelitis patients who have been transferred for rehabilitation. The patient with myasthenia gravis continued to require a tracheostomy due to the persistent bulbar palsy. The tracheal stenoses in the two patients with tetanus are responding to conservative measures, and the patients follow the normal activities of school boys, except for swimming.

Respiratory Management and the Anesthesiologist

The training of an anesthesiologist engraves the importance of a clear airway and adequate pulmonary ventilation on his intellect and an abhorrence of obstructing secretions on his observations. The modern practice of anesthesiology provides unrivaled opportunity for experience in applied pharmacology and physiology and the effects of intermittent positive pressure ventilation on respiration, the circulation and the nervous system.

An experienced anesthesiologist, especially if interested in the problems, is best qualified to be responsible for the vital respiratory therapy. This is his function in the operating room. The equipment and facilities for maintaining a clear airway and pulmonary ventilation are familiar to him and can be expertly used and taught to others.

A wide knowledge of the physiology and mechanics of respiration, and the management of the unconscious state and acid-base disorders are basic in his training. Constant practice and experience imparts technical skill

and knowledge which can be life saving in an emergency. Most respiratory units have been developed by an experienced anesthesiologist who performs the bulk of the work in the acute stage.

It is agreed that a clinician is responsible for his actions. If that person is carrying the major clinical load and also is organizing and developing the physical aspects of a unit to manage patients suffering from respiratory failure, he is the obvious choice to be in charge with full responsibility.

Summary

The condition of respiratory insufficiency and practical clinical methods of assessing the adequacy of pulmonary ventilation have been described.

The physiological principles applicable to the emergency ventilatory procedures have been discussed with description of the management required in tracheostomy and in the conditions which can be associated with respiratory failure.

Facilities and staffing necessary for the management of respiratory failure are mentioned with special reference to the contribution the anesthesiologist can make in this interesting and demanding work.

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