EXPERIENCES IN A RESPIRATORY RESUSCITATION UNIT

G. A. ELLIOTT, *Professor of Medicine, University of the Witwatersrand, Chief Physician Johannesburg Hospital, and Director of the Cardiopulmonary Research Unit of the Council for Scientific and Industrial Research ;* AND A. H. RUBENSTEIN, *Medical Registrar ;* D. P. STABLES, *Medical Registrar ;* AND A. W. W. VAN AS, *Medical Registrar ; Department of Medicine, University of the Witwatersrand and the Johannesburg Hospital, and Cardiopulmonary Unit of the Council for Scientific and Industrial Research*

Formal cardiorespiratory resuscitation units at the Johannesburg General Hospital developed from the special requirements of the Thoracic Surgical Department, and from the respiratory physiology studies of the Cardiopulmonary Research Unit of the CSIR in the Department of Medicine. The scattered geographic distribution of clinical departments in the Johannesburg General Hospital has necessitated the establishment not only of a central unit serving about 600 beds in the Ronald MacKenzie block and 80 beds across the road at the non-European hospital, but also units in the Thoracic Surgical Department in a nursing home one block away, the Neurosurgical Department in yet another nursing home 4 blocks away, and in the Transvaal Memorial Hospital for Children half-a-mile away.

The thoracic surgical unit treats cases of stove-in chest,

except those with multiple injuries admitted direct to accident and general surgical wards of the General Hospital. This publication deals only with the respiratory aspects of the unit situated in the General Hospital.

The unit in the main (Ronald MacKenzie) block of the General Hospital falls under the control of the Department of Medicine; it developed through the department's experience in cardiopulmonary research. The unit could not function without the close cooperation of the Departments of Surgery, (particularly its accident service), Thoracic Surgery, Anaesthetics, Plastic Surgery, and Neurosurgery.

It consists of 6 beds in 2 wards of 3 beds each (Fig. 1) each ward having been converted from 2 small 2-bed wards. The size of each ward is 36 ft. by 9 ft. The rooms are narrower than is desirable and should be 2 ft. wider. During the time these wards have been air-conditioned there have been no cases

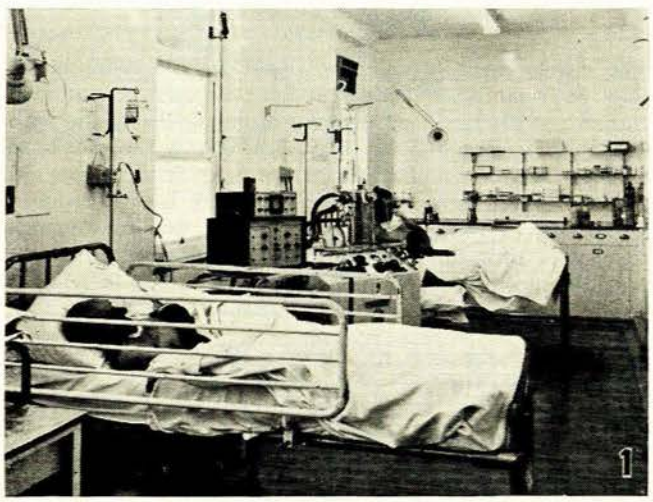

Fig. 1. General view of one resuscitation room. The between-bed screens have been removed for photographic purposes.

of dangerous hyperpyrexia in acute respiratory failure. Equipment for intubation, tracheostomy, tracheal toilet, and artificial respiration, is kept in the unit. Of artificial respirators, there are Ambu bags, 6 Bird respirators, and one Engstrom. Two more Engstroms are on order to replace obsolete equipment collected over the last 3 decades. The Ambu bag, with Rubin's valve, is used during transport of under-breathing or non-breathing patients to or from the unit. The bird respirators are light and portable and are used on short-term and less severe longer-term cases in the unit and in outlying wards. They can supplement hypoventilation by their triggering device or take over respiration and, in the hands of the reasonably technically minded, are sturdy. The Engstrom (Fig. 2), used on severe and longer-term (7-14 days) cases, is a powerful unit, able to deliver over 30 litres of air per minute, excluding supplementary oxygen up to 12 litres per minute, at a maximum pressure of 70-80 cm. water. The pressure is adjusted automatically to deliver the pre-set volume calculated, if the height and weight are known, from a nomogram. The respired volume may be air, or a mixture of air and oxygen up to 100% oxygen. Of the powerful machines, we have standardized on the Engstrom. Standardization has many advantages: the medical and nursing personnel must understand the working of the respirators in use; the nurses must know how to monitor them in the absence of the doctor, and must know when to call the doctor; standardization facilitates maintenance and prolongs the life of the equipment. Other ventilators may be as versatile as the Engstrom.

Oxygen and suction are piped, the oxygen pressure being 60 lb./sq.in (p.s.i.) in the wards (the Bird requires 25-100 p.s.i.) and 5 p.s.i. in the theatres (inadequate for the Bird). There are movable partitions between the beds, aluminium on the lower half and glass on the upper half, extending from the rear wall to within 4 feet of the front wall. These can be hinged back or removed entirely to make room for a portable X-ray set. The patient sexes are mixed (patients are not visible to one another, and the patients are anchored to their beds by a tracheostomy which confines their gaze to the ceiling). A radio call system has not yet been installed.

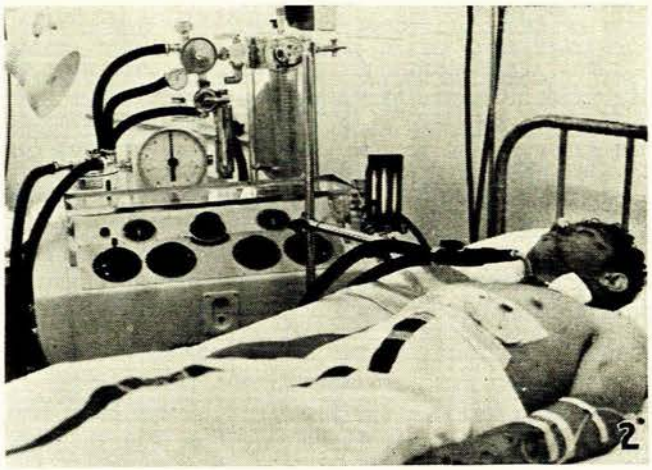

Fig. 2. The Engstrom unit connected to a 'multiple trauma' patient (stove-in chest, compound fractures of limbs, perforated bowel and paralytic ileus).

Across the passage from one of the wards are 2 rooms for laboratory purposes and for housing equipment not in use. The monitoring laboratory equipment measures the pCO_2 of expired air, and pCO_2, pH and CO_2 of capillary blood and of arterial blood. Technical assistance is provided by the Department of Medicine.

Staffing

1. *Medical staff.* The basic medical staff is from the Department of Medicine, and consists of the head of the department and 3 trained registrars. It is hoped to have established a post of Physician (Resuscitation), whose function will be to supervise and carry out with the help of other medical staff the very exacting work of the unit, to instruct doctors and nurses in resuscitation, and to supervise the care and maintenance of equipment; and to be available for consultation in the Casualty Department. Round-the-clock medical service may be necessary, and this is provided by the 3 registrars and by the interns attached to the adjacent wards. There is a roster from the Department of Anaesthetics and from the Thoracic Surgical Department. Staff from the Anaesthetics Department do most intubations, and the Department of Surgery carries out the tracheostomies either in the operating theatre or in the unit, or in the Casualty Department. Tracheostomy can present formidable technical problems in complicated cases.

It is desirable that all cases, once they are actually in the unit, should fall under the care of the unit medical staff. It is confusing, and consequently at times dangerous, for the nursing staff to have a multiplicity of medical staff issuing instructions concerning two or three cases and, furthermore, there are particular aspects of treatment best known through experience to the trained members of the unit.

The type of personality suited for the work deserves comment. Participants must be imperturbable, capable of speedy but wise decision, able to work in a team (this is no place for the individualist), and willing to work with little sleep for days on end. In addition to general clinical knowledge and experience, knowledge and interest in machines and electronics is desirable, and also a knowledge of cardiopulmonary physiology and pathology, and electrolyte and water metabolism.

2. *Nursing staff.* The unit is in the charge of the sister of the adjacent general medical ward. A staff nurse is attached full-time, who, when she is not busy with cases, is kept fully occupied checking and cleaning equipment and checking sup-

plies of expendables. When a case is admitted, a round-the-clock nursing service (3 nurses on 8-hour shifts each) is provided by trained or trainee student nurses. More than 2 cases in the unit necessitates additional nurses. The nurse's work is most responsible, particularly in regard to tracheal toilet and clinical and instrumental monitoring. A proposal to establish a diploma in the nursing of the unconscious patient, including the patient in respiratory failure, has been submitted to the South African Nursing Council.

3. *Medical technological staff.* The Department of Medicine provides the medical technological service.

Purposes of the Unit and the Type of Cases Admitted

The unit is intended for cases of acute respiratory failure mainly, but is also qualified to take care of cardiac emergencies such as standstill, ventricular fibrillation, and severe peripheral failure, and to give advice in these conditions. Equipment necessary for cardiac resuscitation is supplied.

The cases of acute respiratory failure include heavy overdosage with sedative drugs, household gas poisoning, and paralytic poisons such as the organic phosphorus compounds; neuromuscular paralytic states such as porphyria, encephalomyelitis, and myasthenia gravis; chest trauma; severe collapsed pneumonia, and pneumonia and acute bronchitis that have precipitated failure in chronic chest conditions such as kyphoscoliosis or emphysema; status asthmaticus; burns of the chest wall with 'splinting' of chest movement and consequent hypoventilation; post-operative respiratory failure owing to lung collapse, obesity, paralytic ileus or curare hypersensitivity. Head injuries present philosophical resuscitative problems too complex for discussion here. Cases often exhibit multiple pathological states, especially in the older age groups. One patient with stove-in chest, who recovered, had head injuries, paralytic ileus due to retroperitoneal haematoma, chronic hypertension, and diabetes mellitus, and at the time of the accident was on anticoagulants for a carotid artery stenosis diagnosed 4 years previously. Cardiac failure may complicate the picture, and obesity is always a threat to respiratory function in the above-mentioned conditions.

Admission of Cases to the Unit

1. *From casualty.* With only 6 resuscitative beds, clearly there must be a selection of cases. A member of the unit staff, when called, visits casualty to help decide if a case requires direct admission to the unit. If necessary the case is intubated or tracheostomized in casualty. Gastric lavage is never applied in drug coma without a cuffed endotracheal tube in place; after necessary emergency treatment the case is taken to the unit, the Ambu bag being used during transit if necessary.

2. *From the wards.* Cases may be admitted from other wards, surgical or medical, and the unit staff is available to assist in advising on the need for such transfer. Cases that need round-the-clock special nursing *must* be admitted to the unit.

PROGRAMME OF MANAGEMENT

The monitoring of each case of respiratory failure is clinical (cyanosis, mental state, and other signs and symptoms of hypoxia or hypercapnoea) and when necessary laboratory (pCO_2, pO_2 and pH). Laboratory tests, by no means necessary in every case, give useful information in difficult cases. For example, tests may help to decide whether stupor is due to CO_2 retention, toxaemia from pneumonia, brain trauma, or an unduly high artificial ventilation pressure causing a poor return flow of blood to the heart, poor cardiac output, and consequent syncope. The cardiac oscilloscope continuously attached to the pulseless collapsed patient is sometimes the only means of knowing that the patient who is being artificially respirated is indeed alive. Details of the clinical and laboratory aspects of acute respiratory failure appear in an earlier publication.

1. *Airway*

Airway is established as a first measure by a Guedel's tube or, when considered necessary, by cuffed endotracheal tube or by tracheostomy. The cuffed endotracheal tube is left *in situ* not longer than 24 hours. Usually within 12 hours it is known if the tube can be dispensed with or should be replaced by tracheostomy.

The indications for tracheostomy cannot easily be defined. If the patient remains cyanotic in spite of adequate administration of oxygen by nasal catheter, or is pink but in clinical or biochemical hypercapnoea, or if he is fatigued by the hyperventilating effort which enables him to remain adequately oxygenated without hypercapnoea, tracheostomy is indicated. There are other factors influencing the decision. The obese patient plunges more easily into acute respiratory failure than the lean. Bronchitis or pulmonary oedema that will require tracheal toilet may be deciding factors. In chest and neck trauma and burns involving the mouth, throat, neck and chest wall it is better to perform tracheostomy before oedema or surgical emphysema obscures the operation site. When in reasonable doubt do tracheostomy, or, once you have seriously considered tracheostomy, do it. Coma from any cause lasting or likely to last longer than 24 hours may be regarded as an indication for tracheostomy. Reversibility or irreversibility of the cause of the coma is an important consideration.

Tracheal toilet of the tracheostomized patient is of the utmost importance, and both medical and nursing staff must know precisely how to carry it out. We use a Bardic 1761 polythene suction catheter which is rigid enough not to curl up in the face of viscid secretions. By twisting the catheter the right or the left bronchus is entered and sucked at will. 5 - 10 ml. of saline, or more if secretions are very viscid, are instilled into the trachea immediately before the sucking.

Toilet is carried out about every 15 - 30 minutes. In one case of acute pulmonary oedema owing to organic phosphorus insecticide poisoning, toilet was done every 5 - 10 minutes owing to the quantity of oedema fluid that was poured out, blocking the expiratory tube of the Engstrom. Less severe cases need less frequent toilet. Humidification during tracheostomy must under no circumstances be neglected.

A size-9 or larger cuffed James's tracheostomy tube is used for adults. Smaller tubes for the adult must be condemned. They block easily and seriously hinder adequate toilet. Once the rubber tube shows a deposit on the luminal wall, it is destroyed and a new one inserted. The cuff balloons must be carefully inspected for bulges or leaks. If the cuff balloon bulges unequally

as it is filled with air, it may herniate backwards into the trachea, and cause total tracheal obstruction with asphyxia and death if it is not relieved immediately by releasing the air in the cuff. The nursing staff must be specifically warned of this possibility and told how to combat it by deflating and if necessary removing the tube. Pre-operative (tracheostomy) atropine may be dangerous in cases of obstructive chest disease with bronchitis; bronchial secretions become more viscid, bronchial obstruction increases steadily, and the patient may be precipitated into acute respiratory failure of severe degree. In organic phosphorus poisoning the secretion is so liquid that it remains mobile in spite of the atropine, and atropine is, of course, a pharmacological antidote to the cholinesterase-inhibiting poison.

2. *Oxygen*

The indication for oxygen is respiratory failure, or compensated failure, in which arterial oxygen saturation is maintained but only at a cost of fatiguing voluntary over-ventilation. If oxygen administered by spectacles suffices, the case is not one for admission to the unit. Oxygen may be administered through either the endotracheal tube or the tracheostomy, and if that fails to relieve failure or respiratory fatigue it may be given through a respirator in any percentage needed, up to 100% of the ventilation volume.

It is still necessary to emphasize the elementary principle that the oxygen supply and delivery tubes must first be checked if the patient remains cyanosed when apparently on oxygen. Within the patient, obstruction to flow of air may be due to secretions in the tracheostomy or endotracheal tube, or in the trachea and bronchi, or, uncommonly, to herniation of the cuff.

3. *Artificial Ventilation*

The minute ventilation requirement of the patient is calculated from the nomogram if possible. The test of adequacy of ventilation is always, however, the colour of the patient—is he centrally blue or pink?—remembering that absence of cyanosis does not exclude CO_2 retention if oxygen is being administered at the same time, particularly in chronic obstructive lung disease in which the sensitivity of the respiratory centre is further reduced by the oxygen.

When the patient remains in respiratory failure in spite of oxygen and tracheostomy, artificial ventilation is needed. The ventilators in use are described in an earlier paragraph.

Technical failure of a respirator is rare if it is properly serviced. 'Respirator failure' is usually due to the operator's ignorance. The respirator must be examined first if respiratory function continues to fail with the patient on the respirator. A patient on a Bird respirator became more grossly cyanosed and all respiratory movement ceased. The switch was found to be on 'trigger' and not on 'take-over', and the patient being 'respirated' was found, in fact, to be dead. An Engstrom could be heard to be functioning but respiratory failure recurred with no notable observable obstruction in the airways of the instrument or patient. The fillercap of the humidifier had loosened and slipped off and all the ventilated air was being dissipated into the atmosphere. On another occasion some unauthorized interloper switched the oxygen lead to the outside air. Should there be any doubt remove the machine from the tracheostomy and test the volume of pumped air or air and oxygen on the spirometer and see if this approximates to the pre-set delivery volume.

Ventilation pressure requires brief mention. The pressure may be built up purposefully, either gradually in an attempt, usually fruitless, to improve arterial oxygen saturation in organizing contusion of the lung or other alveolar capillary block syndromes, or rapidly for short periods (15 - 20 minutes) in acute pulmonary oedema, either post-traumatic, inflammatory, cardiac, or toxic as in organic phosphorus poisoning. Increase of pressure to 50 - 70 cm. water in acute oedema may be effective. One is happiest when pressures of 20 - 30 cm. water are adequate to maintain respiratory function.

Sudden obstruction in a main bronchus is indicated by a rapid return or persistence of cyanosis in the face of patent tubing and trachea, and by a sudden rise of pumping pressure from, say, 20 cm. water to 50 - 60 cm. A gradually rising pressure may be due to gradually developing bronchial obstruction but is more likely to be due to pneumonia, collapse, inflammatory or traumatic oedema, or organizing contusion.

Inspissated plugs of mucus may cause sudden and serious blockage round about the 5th day of artificial ventilation. This is minimized by adequate humidification and tracheal toilet. An inspissated plug or 'bronchial bullet' that had to be extracted with forceps is shown in Fig. 3.

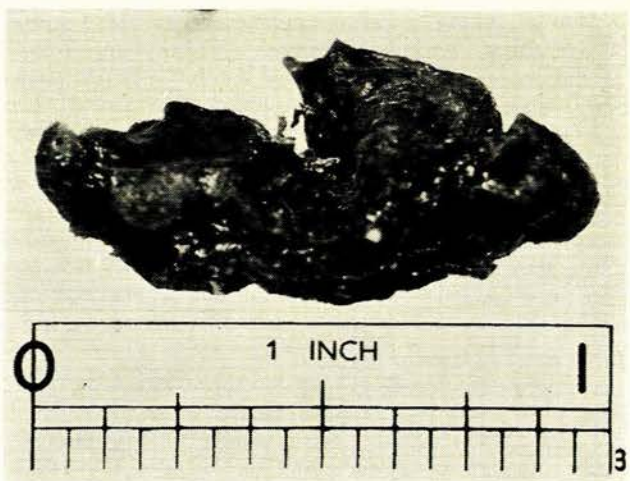

Fig. 3. Desiccated bronchial plug ('bronchial bullet') removed on 5th day from patient in deep barbiturate coma.

Negative ventilation pressures are sometimes, though uncommonly, needed. In emphysema and status asthmaticus not responding adequately to positive pressure only, a negative pressure of minus 3 - 5 cm. water may improve alveolar ventilation. In our experience congestive cardiac failure with raised jugular venous pressure, irrespective of ætiology, is not improved by negative pressure; but our experience is limited in this kind of case.

Weaning from the respirator may be easy or difficult. Occasionally a patient becomes psychologically dependent

upon it. The respirator must be disconnected from time to time as respiration returns, to test if the patient's own respiration is adequate. If the colour remains pink but the patient is seen to be fatigued from the effort of breathing, the machine must be temporarily reconnected to relieve fatigue. The weaning process does not take longer than a day or two in most instances.

4. *Body Temperature*

Temperature must be measured rectally 1 - 4 hourly. This measurement gives fair warning of the precipitate and, if uncontrolled, fatal hyperpyrexia that may occur. Air-conditioned resuscitation rooms have eliminated this complication.

5. *Control of Infection*

In spite of all reasonable aseptic precautions, including proper disposal of the large amount of infective material that collects, infection of the tracheostomy wound and of the lung is all too common in tracheostomized cases. Ideally, every tracheal toilet should be carried out with full aseptic precautions. Such practice requires continuous nursing service for each patient.

The nature of the infection must be established by culture of the tracheal wound and of bronchial washings. In anticipated long-term tracheostomized and ventilated cases immediate antibiotic cover should be started, the initial schedule being adjusted on receipt of culture reports.

6. *Maintenance and Restoration of the Circulation*

This is usually achieved by routine methods.

7. *Removal of Toxins*

Removal of toxins (i.e. toxins that can be excreted by the kidney) through forced diuresis should only be attempted if the renal circulation and output are reasonable. Then only, provided congestive cardiac failure is not present, is it justifiable to administer 10% mannitol intravenously, since increase of circulating blood volume caused by the osmotic diuretic may dangerously aggravate the failure.

Peritoneal dialysis is used in severe cases of drug poisoning if renal output is not satisfactory. It is carried on for 24 - 48 hours. This treatment needs further evaluation.

Exchange blood transfusion as a means of removing circulating toxin was used in 4 cases of deep sedative and in one of household gas poisoning. It restored the circulation rapidly, raised body temperature in a hypopyrexial (body temperature 78°F) case of glutethemide ('doriden') poisoning, and was possibly significantly contributory to the elimination of circulating drug or carbon monoxide. In one case of deep drug coma the exchange was of 15 pints, and in the others 10 - 12 pints. In appreciation of the technical difficulties, all were done personally by the Director of the South African Blood Transfusion Service, Dr. Maurice Shapiro. The input of blood must not be allowed to lag behind or overtake the outflow. In one moribund barbiturate coma patient who recovered, congestive cardiac failure owing to barbiturate myocarditis was present, and as little as 100 - 200 ml. of blood on the credit side caused the veins in the neck, already showing high pressure, to engorge more grossly, and the same amount on the debit side resulted in low systemic pressure and collapse. All cases so treated have recovered. One patient developed a deep-vein thrombosis at the site of the effluent needle. It is impossible to say if the patients would have recovered had no exchange been given. Barbiturate was estimated in the first and the last samples of removed blood, but it was not possible to calculate how much total drug was removed. Control studies will be carried out following this pilot study.

8. *Drugs in Respiratory Failure*

(a) *Respiratory stimulants*. The analeptics nikethemide and bemegride ('megimide') in orthodox doses cause lightening of unconsciousness and return of reflexes, and stimulate respiration. They serve a purpose as a test of the depth of coma and depression of the respiratory centre, and may be of therapeutic value in cases of emphysema with pneumonia and bronchospasm or of drug coma not considered at the time of first examination to be severe enough to require tracheostomy or artificial ventilation, or if ventilation facilities are not available. Their use must not be allowed to deflect attention from the life-saving procedures of tracheostomy and artificial ventilation. If in doubt, do a tracheostomy and ventilate. The therapeutic dose of megimide is not far off its toxic dose, and overdosage may lead to dangerous convulsive seizures, with death. Delusional psychoses may occur when the patient regains consciousness. Nikethemide in obstructive lung disease with respiratory failure has been disappointing in our experience.

Once the patient is safely on a ventilator, analeptic drugs are unnecessary and must not be used. Occasionally death is ascribed to the respiratory failure when it is in fact due to analeptic drugs.

(b) *Respiratory depressants*. When the patient is connected to a respirator that can take over respiration, and is restless and fighting against the respirator, refusing to synchronize with it, and there is no mechanical defect in the ventilator, morphia is given 4 - 6 hourly for as long as is necessary, up to a week. This may be required in stove-in chest, or in heavy drug coma in the recovery phase as restlessness supervenes, or even in emphysema with pneumonia.

Through a suitable ventilator such as the Engstrom, 20 - 25% nitrous oxide can be included in the ventilation volume as a sedative. The gas can be blown off in a matter of minutes once sedation is no longer needed. It had a 'laughing gas' effect in one case.

(c) *Bronchodilators* were, uncommonly, used in status asthmaticus once tracheostomy and artificial ventilation had been instituted. The atropine risk has already been mentioned.

9. *Special Comments*

Stove-in chest with paradoxical flail movement of the affected side or sides is best treated by artificial ventilation via tracheostomy. The Bird is adaptable for this purpose with some technical dexterity, but the more powerful Engstrom is the ventilator of choice. Those unaccustomed to its potential are surprised to see how it takes over respiration and causes good movement of the chest, fractured ribs and all, without pain to the

patient. Sedation with morphia may be necessary initially to help the patient to synchronize and may have to be continued for up to a week in severe cases. The prognosis in stove-in chest depends more on the pathological condition of the underlying lung (contusion, oedema, pneumonia) than upon the condition of the chest wall. One case of stove-in chest, with early X-ray signs of severe contusion of both lungs, failed to respond to treatment, and attempts to improve arterial saturation by raising the ventilation pressure to as high as 70 cm. water were ineffective; the patient died 3 weeks later in respiratory failure. At clinical examination in the last week diffuse sticky crepitations were heard, and the suggestion that these were due to organizing contusion was confirmed at the postmortem examination.

The early diagnosis of pneumonia, collapse, contusion, oedema, is essential, and portable chest X-ray apparatus is indispensable. Clinical signs in the chest are difficult to detect and interpret if the patient is on a ventilator.

A remarkable finding has been the improvement in mood that patients who have recovered from deep self-induced drug coma frequently show. Psychotic depression has frequently lifted. It seems possible that the profound hypoxia present before the institution of resuscitative treatment may have a good therapeutic effect on the psychotic state.

Massive haemorrhage of the gastro-intestinal tract has been an unpleasant complication, in status asthmaticus previously on steroids for example.

SUMMARY AND CONCLUSIONS

The proper management of acute respiratory failure demands accuracy in the diagnosis of both the failure (by clinical and if necessary by laboratory means), and the actual and predisposing causes of the failure, which are outlined.

Both the machines and the patient must be monitored, and this monitoring requires considerable general clinical and physiological knowledge and experience. The administration of oxygen and the establishment of airways are discussed with special reference to the indications for tracheostomy and the management of the tracheostomized patient. Humidification of bronchial secretions, tracheal toilet, clinical and instrumental indications of airway blocks, and the use of respirators, are discussed, and also the indications and contraindications for the use of analeptics, sedatives, and atropine.

The management of respiratory failure is always a matter of close cooperation between many medical disciplines and the nursing profession.

Specialized units not only provide good treatment but also act as a stimulus to raise the standard of resuscitative practice in any hospital.

The unit developed through the research facilities provided over the years by the Council for Scientific and Industrial Research. The authors acknowledge the permission of the late Dr. K. F. Mills, Medical Superintendent of the Johannesburg Hospital, to publish this paper. Dr. H. A. van Hasselt has been tireless in giving his invaluable advice. Miss E. Payn, Principal Matron at the Johannesburg General Hospital, is specially thanked for her tireless cooperation in providing the special nursing services at periods of critical shortages of nursing staff. The photography is by the Photographic Unit of the Department of Medicine.

REFERENCE

1. Elliott, G. A., Kamener, R., Zwi, S., Eagle, C. C. P., Obel, I. W. P., Goldman, H. I. and Bruyns, C. (1960): Med. Proc., **6**, 402.