Clinical Practice and Physiology of Artificial Respiration

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Preface

Long term artificial respiration became a practical proposition with the development of the tank respirator in the 1930's. In the next decade intermittent positive pressure respiration (I.P.P.R.) began to be used routinely during anaesthesia, and in 1952 Lassen and Ibsen, faced with an epidemic of poliomyelitis, introduced I.P.P.R. for long term artificial respiration. Since then I.P.P.R. has increasingly but not completely displaced the tank respirator. In this book we describe our experience in the Respiration Unit in Oxford. We give an account of the routines we have used, and summarise the research undertaken to put our treatment on a more reasonable basis. Much of this research was done by Dr L. H. Opie and Dr W. E. Watson while they were research assistants in the Department of Neurology, and we are grateful to them for their extensive contributions.

We welcome this opportunity of thanking others who have helped us, and in particular Dr W. Ritchie Russell, Professor Sir Robert Macintosh, Dr D. J. C. Cunningham, Mr B. B. Lloyd, Dr Grant de J. Lee, Miss Mair S.R.N., Miss A. Symons M.C.S.P., and Mr Tugwell. The National Fund for Research into Poliomyelitis and other Crippling Diseases financed a large part of the research, and the Nuffield Provincial Hospitals Trust built the ward and laboratories.

Contents

CHAPTER I

Normal and Artificial Respiration

NORMAL RESPIRATION

In normal respiration the flow of air in and out of the lungs depends on the pressure changes that result from changes in the volume of the thoracic cavity. In normal inspiration the diaphragm descends, increasing the vertical dimension of the thoracic cavity; the lower ribs swing laterally, increasing mainly the transverse diameter of the thoracic cavity; and the upper ribs swing anteriorly, pushing the manubrium sterni forwards and upwards, and in-

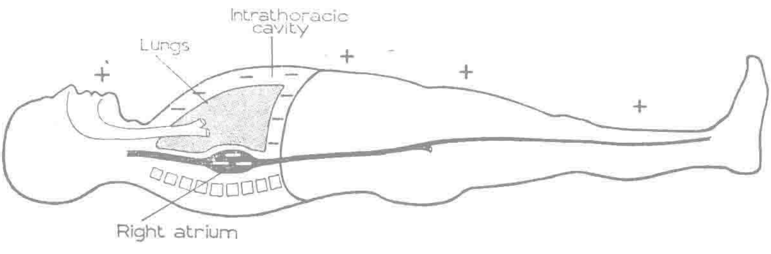

FIG. 1.1. Inspiration of a *normal subject*. Relative pressure in the atmosphere + and the intrathoracic cavity −. Intrathoracic pressure is applied to the lax-walled right atrium.

creasing mainly the antero-posterior diameter of the thoracic cavity. The volume of the thoracic cavity is therefore increased, and the intrathoracic pressure, that is the pressure in the intrapleural spaces and the mediastinum, falls below atmospheric pressure (Fig. 1.1). Air at the nose and mouth is at atmospheric pressure, and therefore it flows to the region of lower pressure in the chest, and the lungs are inflated. The lungs, however, are elastic and require a given pressure to inflate them a given amount. In the normal subject a pressure of 1 cm water will distend the lungs 200 ml, that is, the *compliance* is nearly 200 ml/cm water. To state the same thing another way, about 5 cm water pressure is required to introduce 1,000 ml into the lungs, that is the *elastic resistance* (*elastance*) is 5 cm water/l. (see Chapter IV). Inspiration stops when the pressure required to inflate the lungs equals the difference between the pressures in the intrapleural space and in the airway.

The flow of venous blood into the right atrium is also influenced by the fall in intrathoracic pressure during inspiration, for the wall of the right atrium is a lax structure and the intrathoracic pressure applied to its outer surface is transmitted to its lumen. When the intrathoracic pressure falls during normal inspiration, the difference between the pressure in the peripheral veins and in the right atrium is increased, so that the blood flow from the peripheral veins to the atrium is accelerated (Brecher 1956). The result which follows reversal of this pressure gradient is seen in an extreme form in the Valsalva manoeuvre. In this manoeuvre the intrathoracic pressure is voluntarily raised to such a level that venous return, and therefore cardiac output, falls so severely that the subject may lose consciousness. Artificial respiration by intermittent positive pressure or in a tank respirator is a series of minor Valsalva manoeuvres, and its effect on the circulation is described in Chapter VI.

THE TANK RESPIRATOR

(Cabinet respirator, 'iron lung')

The tank respirator is the apparatus which first made prolonged artificial respiration a practical matter. The patient is placed in a rigid tank from which only his head protrudes (Fig. 1.2), and an air-tight seal is made round his neck. To provide inspiration the bellows is expanded so that the pressure in the tank becomes subatmospheric. Pressure in the patient's upper airway is atmospheric so that air flows along the trachea into the lungs. This flow of air continues until the lungs are sufficiently inflated for the elastic resistance of the lungs and the paralysed chest wall to equal the difference between atmospheric pressure and the pressure within the tank. The intrathoracic pressure lies between the pressure in the trachea and that within the tank, its precise level depending on the elastic resistance of the lungs and chest wall (Chapter IV).

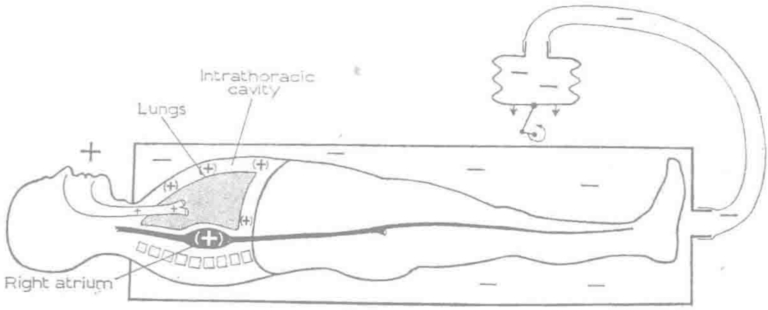

FIG. 1.2. Inspiration of a paralysed patient in a *tank respirator*. Relative pressure in the atmosphere +, intrathoracic cavity (+) and around the patient's limbs and trunk (intra-tank pressure) −. Intrathoracic pressure is applied to the lax-walled right atrium.

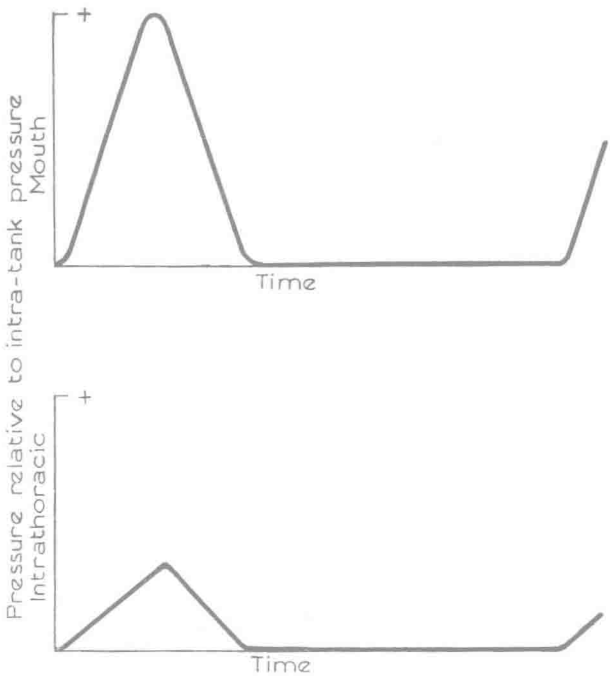

FIG. 1.3. Artificial respiration in a tank respirator. Mouth and intrathoracic pressure *relative to the intratank pressure*, that is the pressure applied to the patient's limbs and trunk. The (intrathoracic) pressure applied to the right atrium is greater than the (intratank) pressure applied to the limbs and trunk.

It is sometimes argued that artificial respiration in a tank respirator is 'physiological' because subatmospheric pressures exist in it and in normal respiration. If the effect on venous return is considered it is clear that this argument is unsound. When a patient is in a tank respirator, the intrathoracic pressure during inspiration is higher than the intratank pressure which is applied to the trunk and limbs and their veins (Fig. 1.2) (Fig. 1.3). The pressure gradient between intrathoracic structures and peripheral veins due to inspiration in a tank respirator is therefore the reverse of that during normal respiration. It follows that inspiration in a tank respirator does not assist but tends to impede venous return.

The principal use of the tank respirator is for patients with weakness of the respiratory muscles, in whom there is no danger that the airway may become obstructed. Its disadvantage is that it is cumbersome and the patient is rather inaccessible.

THE CUIRASS AND THE BREATHING JACKET

The cuirass and the breathing jacket employ the same mechanical principle of artificial respiration as the tank respirator. Although

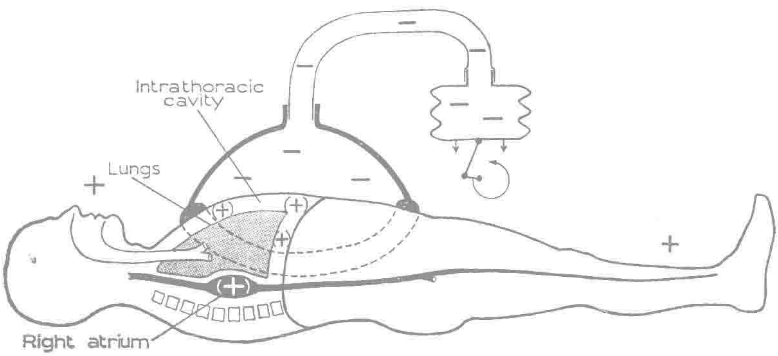

FIG. 1.4. Inspiration of a paretic patient with a *cuirass*. Relative pressure in the atmosphere +, intrathoracic cavity (+), and within the cuirass −.

they are relatively light and mobile they are also less efficient, and are unsuitable for treating acute cases of respiratory paralysis. The cuirass consists of a shell (Fig. 1.4) with rubber round the edge to form an airtight seal with the skin. A bellows or other device, considerably less powerful than that required for a tank respirator, produces subatmospheric pressure in the shell and over the front of the chest and abdomen. Atmospheric pressure forces air into the chest as it does when the tank respirator is used. In the normal subject when the rib cage expands the manubrium sterni moves forward and the lower ribs swing laterally, but when a cuirass is

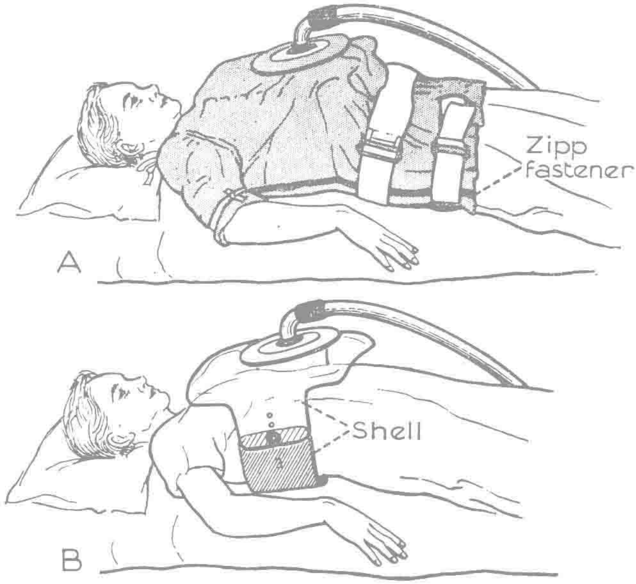

FIG. 1.5. Tunnicliffe breathing jacket. (A) The jacket in use. (B) The plastic shell which holds it clear of the trunk. (Spalding and Opie 1958.)

used, its edge passes over these regions so that instead of causing the ribs to move it is more likely to splint them. Inspiration with the cuirass is therefore largely diaphragmatic, and as the diaphragm descends the abdominal wall protrudes. Cuirass respirators are sometimes known as chest respirators, but as almost their sole function is to produce 'abdominal' respiration this name is not appropriate.

The breathing jacket (Fig. 1.5) is in many ways similar to the cuirass, but it splints the chest less markedly. For a given pressure change, therefore, it introduces into the chest more air than the cuirass though less than intermittent positive pressure respiration (Fig. 1.6). Its disadvantage is that it is less convenient than the cuirass to apply.

Venous return is impeded less by the cuirass and the breathing jacket than by the tank respirator or intermittent positive pressure

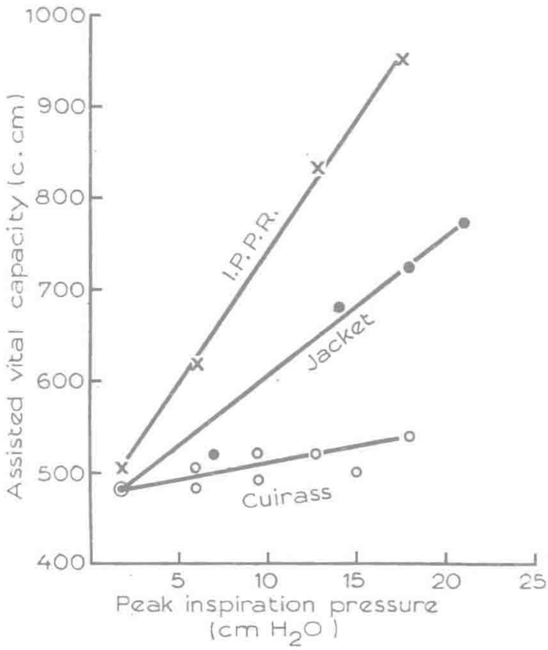

FIG. 1.6. Assisted vital capacity of patient with poliomyelitis at various peak inspiratory pressures with intermittent positive pressure respiration, breathing jacket and cuirass (Spalding and Opie 1958).

respiration. The cuirass and breathing jacket, however, are suitable only for treating patients in good general condition, and in such patients there is rarely any anxiety about venous return.

The principal use of the cuirass and the breathing jacket is for the patient who can breathe many hours unaided, but needs assistance when he is asleep and perhaps for a part of the day.

THE PATIENT WITH A TRACHEOTOMY

The methods of artificial respiration described above, and indeed normal respiration itself, are entirely dependent on a clear airway. The danger that the airway may become obstructed at some level, is the principal indication for tracheotomy, a subject which is more fully discussed in Chapter II. If a tracheotomy has been performed, it is possible to continue artificial respiration in a tank respirator, but there is the disadvantage that the patient is relatively inaccessible and immobile. In most European countries, therefore, when the patient has a tracheotomy, artificial respiration is given by intermittent positive pressure respiration through the tracheotomy. Some centres, especially in America, have become so expert in the management of the patient in a tank respirator that they continue to use the tank respirator even when there is a tracheotomy. This is a special situation which does not reflect a choice based on fundamental principles.

INTERMITTENT POSITIVE PRESSURE RESPIRATION (I.P.P.R.)

I.P.P.R. can be given through an endotracheal tube passed through nose or mouth. The larynx, however, will not tolerate the presence of a tube indefinitely, and 24 hours is probably as long as it should be left. For long-term I.P.P.R. therefore it is necessary to introduce gas into the lungs through a tracheotomy. It is usual, at least when the patient is acutely ill, to use a tracheotomy tube with a cuff which is inflated to make an airtight seal with the walls of the trachea (Fig. 2.4B, p. 24). This serves two purposes. It prevents saliva, vomit, or other foreign material from passing from the pharynx into the chest, and it prevents air which is blown into the chest from leaking up through the nose and mouth. The tracheotomy tube is connected to tubing from a respirator, which during inspiration provides a pressure above atmospheric pressure. Air passes into the chest until the pressure in the airway is balanced by the elastic resistance of the lungs and chest wall. The intrathoracic pressure is raised, but less than that in the airway

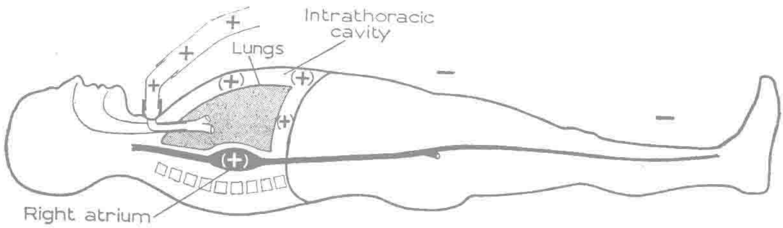

FIG. 1.7. Inspiration of a paralysed patient with *I.P.P.R.* Relative pressure at the tracheotomy +, in the atmosphere − and within the thoracic cavity (+). As with the tank respirator the (intrathoracic) pressure applied to the right atrium is greater than the (atmospheric) pressure applied to the limbs and trunk.

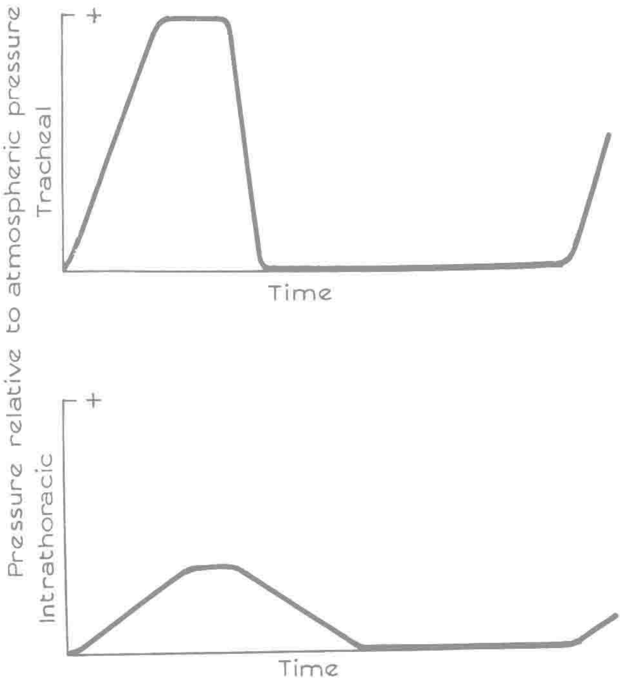

FIG. 1.8. *I.P.P.R.* Tracheal and intrathoracic pressure relative to the (atmospheric) pressure applied to the limbs and trunk.

(Fig. 1.7). The intrathoracic pressure is therefore higher than the (atmospheric) pressure applied to the trunk and limbs and their veins, so that I.P.P.R. impedes the venous return during inspiration in precisely the same way as a tank respirator. Fig. 1.3 and Fig. 1.8 are records of airway and of intrathoracic pressure compared to the pressure applied to the surface of the body. They are therefore comparable records of the forces impeding venous return when the tank respirator and I.P.P.R. are used.

The effects on venous return of I.P.P.R. and the tank respirator can be mitigated by assisting venous return during the period between inspirations. To do this with I.P.P.R. the tracheal pressure must be subatmospheric, and with the tank respirator the intratank pressure must be above atmospheric. The extent of the effect on venous return and the need to employ these measures is discussed further in Chapter VI. In our experience, however, the great majority of patients with respiratory failure can be treated satisfactorily with I.P.P.R. without subatmospheric pressure during expiration.

The principal use of I.P.P.R. is for the patient who not only requires artificial respiration but also requires a tracheotomy for one of the reasons described in Chapter II.

BELT RESPIRATOR

Paul Bragg Pneumobelt

In the types of respirator considered so far force is applied to produce inspiration, but in the belt type of respirator the force applied by the apparatus produces expiration. The normal subject starting with the chest in the resting position can inspire about 3,000 ml, but from the resting position he can expire only about 1,000 ml. It is impossible, therefore, for an expiratory form of artificial respiration to produce as much ventilation as an inspiratory form, but nevertheless in favourable circumstances it might in theory produce a tidal volume sufficient to meet the patient's needs. In practice these respirators consist of a wide inflatable belt round the lower chest and the abdomen, and a pump which intermittently inflates the belt. As the belt distends, it presses on the abdomen and forces the diaphragm up. Inspiration occurs when the diaphragm descends either by muscular action, or, if the patient is sitting up, by gravity.

The principal use of a belt respirator is for patients who need some assistance to spontaneous breathing. Its advantages are that the belt is inconspicuous and simple to apply, and the whole apparatus is small and light and can be run from a car-type accumulator. As it assists the diaphragm it is most useful for the patient whose intercostal muscles are preserved but whose diaphragm is paralysed.

ROCKING BED

In this form of artificial respiration a motor rocks a bed alternately head up and head down. When the patient is steeply head down, the abdominal contents force the diaphragm in a cephalic direction and expiration occurs; when he is head up the abdominal contents and the diaphragm descend, resulting in inspiration. A total travel of 40° is satisfactory, but small angles of tilt may provide almost no artificial respiration.

The principal use of the rocking bed is to assist the patient who cannot breathe adequately on his own, and it is particularly helpful at night. The patient on a rocking bed often has a false but satisfying feeling that he is now weaned from artificial respiration. As with belt respirators the rocking bed is most suitable for a patient whose intercostal muscles are active and whose diaphragm is weak.

GLOSSO-PHARYNGEAL BREATHING
'Frog-breathing'

Glosso-pharyngeal breathing is a method of breathing which requires none of the muscles usually considered as respiratory. Air is taken into the mouth, forced into the chest, and held there while the process is repeated (Fig. 1.9). When a sufficient tidal volume has been forced into the lungs, it is allowed to flow out passively. With a deep glosso-pharyngeal breath the rise in intrathoracic pressure may impair venous return, and patients should be warned to breathe out if they feel dizzy.

The principal use of glosso-pharyngeal breathing is for the patient with permanent and severe weakness of the respiratory muscles.

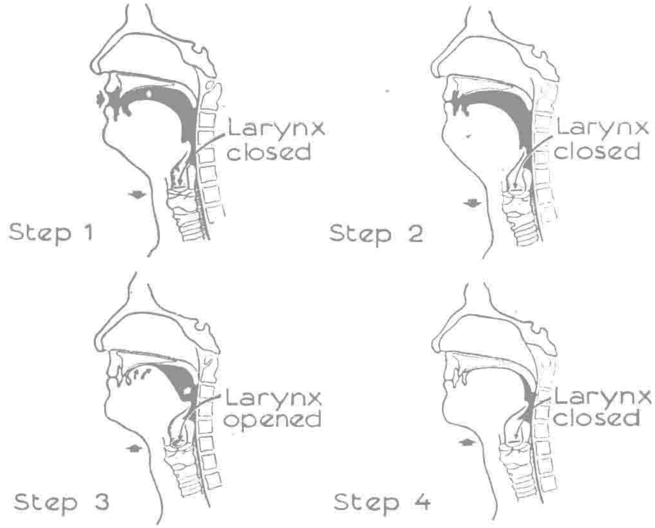

FIG. 1.9. Steps taken during one 'stroke' of glossopharyngeal breathing. Step 1, a mouthful and throatful of air is taken, depressing the tongue, jaw and larynx to get maximum volume. Step 2, the lips are closed and the soft palate raised to trap the air. Step 3, the jaw, floor of mouth and larynx are raised. This together with progressive motion of the tongue forces air through opened larynx. Step 4, after as much air as possible is forced through the larynx, it is closed and the air is retained in the lungs until the cycle is begun again (Dail, Affeldt, Collier 1955).

The extra respiration it provides enables the patient to cough more effectively, to cope with emergencies, and to be temporarily parted from a respirator with more safety and confidence. Patients with no spontaneous respiration and those with a tracheotomy often have difficulty in benefiting from glosso-pharyngeal breathing.

CHAPTER II

Practice of Artificial Respiration

1. INITIAL STAGES

Most patients admitted to the Respiration Unit in Oxford are referred from another hospital or less commonly by a general practitioner. A patient with respiratory difficulties can travel safely, if cared for by an anaesthetist who has the necessary knowledge and equipment, and can therefore be moved to a centre where special facilities are available. It is, however, dangerous to put him into an ambulance without proper care merely to get him to a Respiration Unit quickly. The patient can make the best use of his remaining powers if he is in bed in the position of his choice, but if he is laid supine on a stretcher, wrapped tightly in blankets and bumped about in an ambulance, respiratory failure can be precipitated. An anaesthetist in the patient's area may be prepared to supervise his transfer, but in our region a team from the Respiration Unit can reach the patient within two hours of a request for assistance being received. A consultant neurologist or consultant anaesthetist usually goes to the patient with a registrar from the other speciality and in this way experience of this work is disseminated in both departments. The team takes with it a source of I.P.P.R., a suction apparatus and equipment for endotracheal intubation under general or local anaesthesia. This equipment can be carried in almost any car and details of it are given in Chapter XI. If there is doubt whether the team from the Respiration Unit can reach the patient in time, assistance is requested from an anaesthetist in the patient's vicinity. If the anaesthetist is not used to this kind of work, special difficulties which may arise may be discussed with him by telephone. If the patient is more than two hours' travelling time from the Respiration Unit, these arrangements may have to be modified, and in particular if a tracheotomy is indicated