Respiratory failure after cardiac surgery

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Preoperative assessment

Extremely important in the postoperative management of respiratory failure is preoperative assessment and the recording of baseline information. Preoperative arterial blood gases provide important baselines so one may judge what is normal for that individual patient postoperatively. In the adult, a history of chronic obstructive pulmonary disease will tell one that the patient will have difficulty postoperatively and that a PCO_2 of 50, for example, may represent his normal value. In a child a history of Down's syndrome, for example, will mean that the patient will have difficulty with postoperative secretions and atelectasis. We use to perform pulmonary function tests in adults preoperatively but found them of very little use partly because the cardiac disease preoperatively affects the test. Baseline arterial blood gases and history are far more important.

Intraoperative management

What one does with the lungs intra-operatively has a great deal to do with postoperative difficulties. Available evidence suggests that the lungs should be left statically inflated to a low pressure of 5 to 10 cmH_2O during perfusion and not be gently ventilated as use to be the case. Trauma to the lungs in the operating room should be avoided. This is usually not a problem with a median sternotomy incision but is more of a hazard with a lateral thoracotomy. For example, in a patient having resection of a aneurysm of the descending aorta with partial left heart bypass, trauma to the left lung is a potential problem. This may be avoided by use of a split endotracheal tube so the left lung may be collapsed during the procedure. Exposure is provided with traction sutures and packs not with metal retractors and the lung is not reinflated until the heparin has been reversed.

Attention to such intraoperative details will result in a clear postoperative chest roentgenogram and a much smoother course than if there is hemorrhage or atelectasis in that lung. Similar principles hold true for other patients such as infants undergoing Blalock-Hanlon operations in which the lungs should be handled very gently and the right pulmonary artery securely occluded while the clamp is applied so that venous congestion does not occur.

In the early days of open heart surgery a syndrome called "post perfusion lung" was described consisting of fluffy infiltrates in the lung and respiratory insufficiency. This syndrome has disappeared from surgical practice with the realization that the left ventricle must not be allowed to become distended with blood during perfusion so that the left atrial pressure and pulmonary venous pressure become excessive with resulting pulmonary edema. Use of a left ventricular vent when the heart is fibrillating, will prevent this. It may be placed in the apex. through the pulmonary vein or in the aortic root when it is clamped. A single large venous return cannula placed in the right atrium can also effectively decompress the entire heart.

A decision must be made at the end of the operation as to whether prolonged ventilation is desirable postoperatively. Certain patients should be routinely ventilated:

(1) Patients with poor myocardial function who are expected to have unstable hemodynamics postoperatively in whom one certainly does not want respiratory instability to compound hemodynamic problems. Examples are patients with mitral valve disease, or those with complex congenital abnormalities in whom studies have shown that there is usually a 48 to 72 hour period of depressed cardiac output postoperatively.

(2) Patients with severe pulmonary hypertension. Acidosis, hypercarbia, and hypoxia, are potent pulmonary vasoconstrictors and must be prevented by adequate postoperative ventilation.

(3) Patients with central nervous system depression, a very long operation, or a history of lung disease preoperatively. Normally about 5% of the total oxygen consumption is devoted to the work of breathing itself. In patients with chronic lung disease or pulmonary hypertension with stiff lungs the work of breathing may require as much as 20% of the total cardiac output. This is clearly undesirable in pa-

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tients with depressed myocardial function.

(4) In our institution we use a great deal of morphine anesthesia for very sick patients because of its lack of myocardial depression. These patients cannot be extubated immediately postoperatively.

Certainly there are many patients in whom none of this is necessary. The usual patient having a coronary artery bypass or atrial septal defect repair or patent ductus closure may be very quickly extubated postoperatively if an appropriate anesthetic is used. However, the general policy in our institution is to ventilate all patients who have had open heart surgery for several hours or even overnight until the nature of their postoperative course is clear.

We have the problem of transporting patients by elevator from the operating room to the intensive care unit. During this hazardous time the endotracheal tube should be left in even when one plans to remove it immediately on arrival in the intensive care unit.

Ventilation in the Intensive Care Unit (ICU)

Establishing proper mechanical ventilation when the patient first arrives in the ICU is another hazardous period when the physician responsible for the patient must be especially alert and not leave decisions to the respiratory therapists and nurses. Although a tidal volume of 10 ml/kg and a rate of 10 for adults to 20 for infants provide useful starting points, one should not rely on such numbers in making initial ventilator settings. Rather one should make a clinical judgment based on looking at the chest excursions and listening to the breath sounds. Then one should adjust ventilation until it "looks right". This is necessary because the pulmonary compliance varies considerably from patient to patient.

In babies the compliance of ventilatory tubing is also an important variable. One should err on the side of overventilation for even a brief period of underventilation may provoke irreversible pulmonary vasoconstriction in some patients.

There are many adequate ventilators now available commercially which provide several important features. Air and oxygen must be blended to allow a precise determination of the inspirited oxygen concentration (FIO_2). Effective humidification of the gases must be provided. This is absolutely critical in infants with small tubes which become easily plugged. The ventilator should have built-in provision for either controlled ventilation, patient triggered ventilation, positive end expiratory pressure (PEEP), or intermittent mandatory ventilation (IMV). There must also be a reliable alarm. The Baby Bird ventilator is very satisfactory for use with babies since it incorporates all of these features. In adults we use Bennett MA-1 or MA-2 ventilators. The modern versions have built in provision for PEEP and IMV. We prefer volume controlled ventilator such as these to pressure-cycled machines for use in adult patients.

Our standard method of ventilating patients, both adults and children, now is IMV. (fig. 1). This method combines the features of controlled ventilation with continuous positive airway pressure (CPAP that is using PEEP in a spontaneously ventilating patient). With controlled ventilation, of course, the patient is subjected to periodic positive pressure from the ventilator to expand his lungs, whereas with CPAP the patient is ventilating spontaneously with whatever end-expiratory pressure one wishes to impose (typically 5-10 cm of water). Initially, with IMV, one can completely control the ventilation by having the machine cycle sufficiently frequently to keep the arterial PCO_2 below normal. To wean the patient from the ventilator one simply reduces the "back-up rate" progressively until the PCO_2 rises to normal and the patient begins to breathe spontaneously. This permits a very smooth transition from total control to weaning to spontaneous breathing which is far superior to the old method of intermittently taking the patient completely off the ventilator for periods of time. After the IMV has been reduced to zero and the patient is breathing completely on his own then the PEEP is reduced to 2 to 3 cm H_2O showing that the arterial PO_2 will remain adequate while this is done. Than the patient may be extubated and given a face mask.

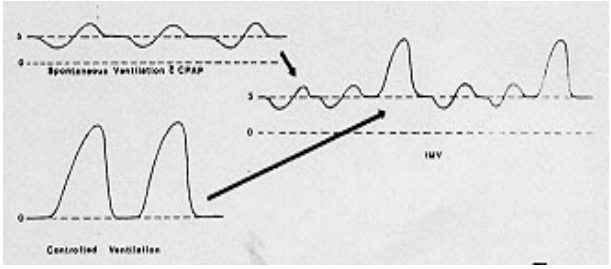

Fig. 1 - Airway pressure with spontaneous ventilation c CPAP, controlled ventilation, and IMV (reproduced by permission of Little, Brown and Company).

Weaning from the Ventilator

Weaning from the ventilator is not begun until the patient meets certain criteria: (table 1) he must be alert, recovered from anesthesia, stable hemodynamically, and not acidotic. Chest tub drainage must be acceptable (it is silly to extubate a patient if one is going to reoperate on him in one hour). The left atrial pressure must be reduced to the appropriate levels. In adults a left atrial pressure over 25 generally will cause pulmonary edema if the patient is taken off positive pressure. In children the left atrial pressure should be less than 15 before weaning is begun. Chest x-ray must not reveal a pneumothorax, atelectasis, or a major fluid collection. The alveolar arterial oxygen gradient ($A\text{-}aDO_2$) must be appropriate (see below). Normally,

the arterial PO_2 should be greater than 300 mmHg in 100% oxygen before one considers weaning (unless the patient has an obligatory intracardiac right-to-left shunt). The patient should be able to generate an inspiratory force of at least 20 mmHg and have a vital capacity of 10 cc/kg.

Table I - Criteria for weaning.

1.	Alert, stable hemodynamics, not acidotic
2.	Chest tube drainage acceptabme
3.	LAP < 25 mm Hg
4.	Chest x-ray OK
5.	PAO_2 > 300 mm Hg on FIO_2 of 1.0
6.	Inspiratory force > 20 mm Hg
7.	Vital capacity > 10 ml/Kg

LAP = left atrial pressure; FIO_2 = inspired oxygen concentration.

Treatment of specific abnormalities in blood gases

If the arterial PCO_2 is too high, one ordinarily simply increases the amount of ventilation. The only exception to this is the child with a big right-to-left shunt where sometimes the pulmonary blood flow is so low that CO_2 cannot be eliminated. In that instance, increasing the pulmonary blood flow and not the ventilation is the answer. When the PCO_2 is too low because the patient is overventilated one can, of course, simply reduce the rate or tidal volume. In adults large tidal volumes help prevent atelectasis so, rather than reduce the tidal volume, and run the risk of atelectasis, one can add 50 cc of dead space to the patient's respirator to achieve a 4 or 5 min increase in the PCO_2. This is not very useful in children.

Hypoxia is a more difficult problem to treat. In evaluating the arterial PO_2 the A-aDO_2 is a very useful concept. Normally when one is inhaling 100% oxygen, the arterial PO_2 should be approximately 760 mmHg minus the water vapor pressure minus the PCO_2. In other words, it should be normally 500-600. This theoretical maximum is rarely achieved in postoperative patients.

The human lung is meant to function in an upright position with most of the perfusion going to the base. When one places a patient in supine or lateral position, one interferes with the normal ventilation-perfusion ratio adversely and some capillaries are perfused but not ventilated while some ventilated segments are not perfused. This is responsible for the so-called normal physiologic shunting and means that most patients postoperatively will not have an arterial PO_2 much more than 300-400 mmHg while breathing 100% oxygen. The final common pathway for all kinds of trauma to the lung is an increase in lung water. Patients who have had cardiopulmonary bypass, transfusion, or just positive pressure ventilation tend to accumulate water in the lungs with the passage of time.

Many cardiac patients have increased left atrial pressure and a hormonal setting which strongly favors fluid retention. Increase in lung water is by far the commonest reason for poor pulmonary compliance and a decreased arterial PO_2 postoperatively and many of our postoperative protocols are designed to deal with that problem. Fluid restriction is essential as is diuresis with such agents as furosemide PEEP is an extremely useful method of treating the increased A-aDO_2. It is thought to open up microatelectasic portions of the lung. Some people believe in administering concentrated albumin to increase the osmotic pressure of the plasma in a: effort to draw water out of the lung by the Fick principle. Personally I am not convinced that this is very useful. There are other mechanical adjuncts such as elimination of atelectasis through physiotherapy, relief of pneumothorax or hemothorax that one must consider when the PO_2 is lower than in should be before weaning from the ventilator is initiated.

Extubation

When the patient has been successfully weaned by the use of IMV, a decision must be made as to extubation (table II). First thing is to place the patient on spontaneous respiration through the endotracheal tube for at least one hour. During that period of time the patient should not be dyspneic and should breathe at a normal respiratory rate. In infants one must look for subtle signs of distress flaring of the nose, sternal retraction, etc. An adult can be questioned: is he air hungry, is he getting enough air to breathe? The arterial PCO_2 should be in a normal range for that patient based on a know ledge of his preoperative values. The arterial PO_2 must remain above 100 mmHg for the usual patients on 40% oxygen. The patient with a right-to-left intracardiac shunt is an obvious exception. Also in older patients one might accept a lower value. Again the preoperative PO_2 which is normal for that patient will help make that decision. Finally, a patient should not be extubated unless he can maintain his PO_2 without PEEP.

Table II - Criteria for extubation.

1. Not dyspneic, normal respiratory rate
2. $PACO_2$ < 45 mm Hg after 1 hr spontaneous respirations
3 - PAO_2 > 100 mm Hg on FIO_2 of 0.4
4. PEEP < 5 cm H_2O

FIO_2 = inspired oxygen concentration; PEEP = positive and expiratory pressure.

Prolonged ventilation

Previously there was fear of damage to the vocal chords or to the trachea from prolonged incubation and tracheostomies were done frequently. Now they are done very rarely because nasotracheal and endo-tracheal tubes are made from nontoxic materials and have low pressure cuffs. There are no absolute

rules about how long a patient may be safely ventilated through an endotracheal tube. In adults after a week of ventilation if extubation does not appear imminent, tracheostomy should be performed through a high incision. A major concern is the potential for infection of a mediasternotomy incision. Because of our experience in neonatal intensive care, we have increasing confidence in ventilating small babies through nasotracheal tubes for even several weeks.

Pulmonary physiotherapy is essential in the prevention of atelectasis and secretion accumulation postoperatively. Vibration and percussion in the ICU should be carried out at least 4 times a day or more often in patients with problems. Trained physiotherapists should be available 24 hours daily and nurses are also instructed in the proper techniques. Frequent suctioning and full humidity are essential. A plug in an endotracheal tube of a newborn is a sign of poor nursing care and is absolutely unacceptable. In adults bedside bronchoscopy may be useful in difficult secretion problems. With the fiberoptic bronchoscope and appropriate adapter one can bronchoscope the patient through the endotracheal tube without interrupting ventilation and remove secretions from individual lobes.