A FEW PROBLEMS RELATING TO ANAESTHESIA FOR CARDIO-PULMONARY BYPASS PROCEDURES

A STUDY OF 240 CASES

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In the final analysis, the capacity of any heart to withstand stress, including those associated with surgery and anaesthesia, depends almost entirely on the condition of the myocardium which, in the majority of cases submitted for corrective cardiac surgery, has been subjected to varying degrees of hypoxia for prolonged periods. These hearts often display a poor tolerance to drugs having a depressant action on the conducting system, including agents used both for pre-operative sedation and anaesthesia. While adequate sedation is essential to reduce, so far as possible, the metabolic rate and O_2 requirements of the myocardium, severe hypotension may follow the use of pethidine or chlorpromazine in the pre-operative period and sodium thiopentone or halothane with the anaesthetic. Dosage must be carefully assessed for each individual patient and his reactions carefully observed. Halothane, in particular, has frequently been found to produce heart block and other arrhythmias, and hypotension may necessitate its discontinuation and, if necessary, a change to ether or methoxyflurane; sodium thiopentone should always be used sparingly.

Effects of Pre-operative Therapy

Digitalis. Many cases for cardiac surgery require prolonged treatment before they can be considered fit for operation, and intensive digitalization with diuresis is the normal routine. This may profoundly affect the response of the heart to certain anaesthetics. The intensive diuresis which is an important part of the treatment may itself induce potassium depletion, while its discontinuation on the day before operation may precipitate a state of digitalis intoxication.

Out of 197 patients who had been intensively treated with digoxin for periods of 2 months or more before operation, 65 were given halothane in concentrations of 0·5 - 1·0% in the pre-bypass stage of the operation. Of these, 30 showed signs of digitalis intoxication including pulsus bigeminus, heart block and runs of ventricular tachycardia. These arrhythmias responded to the intravenous administration of atropine and discontinuation of the halothane. There was one case of cardiac arrest, which responded immediately to cardiac massage. On the other hand, in 43 cases where digitalis had only been used for a few days before operation, no arrhythmias were encountered before opening the chest.

Beta-receptor blockers. Drugs of this type are now being extensively used, in the pre-operative treatment of cardiac patients, for the control of supraventricular tachycardia. The use of pronethalol for this purpose has been recommended by Johnstone,[1] and by Payne and Senfield.[2] It was found in 5 cases, however, that pronethalol produced a marked bradycardia which failed to respond to atropine, and it seemed that this might introduce a hazard when the reversal of a neuromuscular block by neostigmine is required.

Pulmonary Oedema

Some patients do not respond to pre-operative rehabilitation or may require surgical intervention as a matter of urgency. Such cases may come to operation in a state of frank cardiac failure, and here the most pressing problem relating to anaesthesia is usually pulmonary oedema which makes ventilation of the lungs difficult and may, in extreme cases, virtually drown the patient. When oedema is present the anaesthetic should be given under positive pressure, and aminophyllin (10 ml. given slowly intravenously) may improve the cardiac condition. It has also been found helpful, in some cases, to pass the anaesthetic gases over absolute alcohol.

MANAGEMENT DURING OPERATION

Subject to wide variation in detail, operations using the heart-lung bypass can be divided into 3 stages: (*i*) the pre-bypass stage, (*ii*) the bypass stage, and (*iii*) the post-bypass stage, each of which has a widely differing significance in relation to the management of the anaesthetic.

1. *The Pre-bypass Stage*

During this phase of the operation, the catheters are inserted and the monitoring equipment prepared. There is little surgical trauma before the opening of the chest and the stage is noteworthy mainly on account of its very considerable duration. So far as the anaesthetic is concerned, it is necessary to avoid any method that is likely to add unduly to the cumulative depression in the later stages; this is best met by using light anaesthesia (details of which can be varied to meet individual requirements) combined with muscle relaxants.

It is probably advisable to avoid over-ventilation. Excessive washing out of alveolar CO_2 may lead to the elimination of base and a reduction in the alkali reserve and, in view of the metabolic acidosis which is liable to develop during the bypass circulation, any loss of base is highly undesirable. To ensure adequate arterial O_2 saturation without excessive ventilation the respiratory medium must have a high O_2 content.

2. *The Bypass Stage*

The extracorporeal circulation consists of a double pump and oxygenator. One pump takes blood from the great veins which are isolated from the heart, and the blood then passes through an oxygenator, which performs the function of the lungs; another pump forces it through the arterial system via a catheter placed in the femoral artery. The oxygenated blood cannot re-enter the heart against the closed aortic valves and it finds its way back to the veins via the peripheral capillaries. The coronary blood, which returns to the left auricle direct, is removed by suction and returned to the pump circulation. Heparin, in doses of 1 - 1½ mg./lb. body weight, is added to the circulating blood to prevent clotting. The course taken by the pump circulation, within the body, is illustrated diagrammatically in Fig. 1.

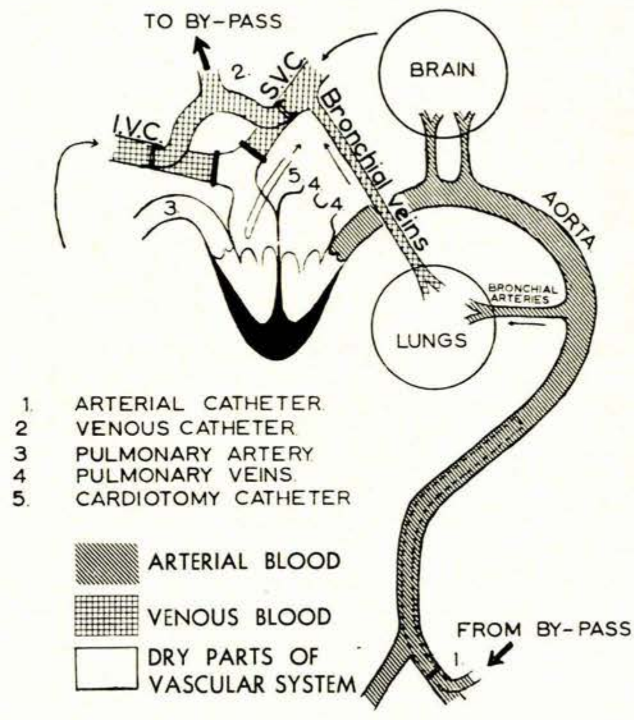

Fig. 1. Diagram illustrating the general path of the circulation during cardio-pulmonary bypass.

Cooling during bypass. In most cases patients are cooled to 30°C during bypass, which gives an almost maximal reduction in tissue O_2 consumption. The temperature is measured by a thermometer which, in most of the earlier cases, was placed in the oesophagus. It has been found, however, that a more accurate index of the brain temperature is obtained with a pharyngeal thermometer. This instrument is passed orally and not through the nose, as nasal haemorrhage can have serious consequences in a heparinized patient.

Anaesthesia. Very little anaesthetic is usually required during this period but, if necessary, a little sodium thiopentone or d-tubocurarine can be added to the pump blood. It is also possible to use anaesthetic vapours in the oxygenator, though this practice was not applied in the cases under review. Experience has shown that, if the patient is given a topping-up dose of d-tubocurarine immediately before going on bypass, no additional anaesthesia is often required until after normal circulation has been restored.

The lungs during bypass. The practice adopted at this stage was to keep the lungs partially inflated, using a 50% mixture of oxygen and helium, to reduce the incidence of postoperative pulmonary atelectasis. Helium is used because it passes through the alveolar membrane with extreme slowness and is retained in the air passages for as long as 19 hours. Owing to its low density, it thus helps to make breathing easier in the postoperative period.

It is also helpful to inflate the lungs almost fully every 5 minutes or so. This is in conformity with the so-called 'sighing technique' of pulmonary ventilation which is widely recommended for intermittent positive-pressure respiration in any type of case. Active ventilation of the lungs during bypass is undesirable, since it tends to pump blood from the pulmonary capillaries into the left atrium where it becomes a nuisance to the surgeon.

On theoretical grounds, it might be expected that the only circulation in the lungs during bypass is through the bronchial vessels. There are, however, important anastomoses between the bronchial and pulmonary arteries and again between the bronchial and pulmonary venules,[3] and, in certain pathological conditions such as tetralogy of Fallot, these anastomotic channels may be developed to such an extent that a major proportion of the bronchial circulation passes through the pulmonary capillaries.[4,5] In certain cases it has been possible to maintain adequate anaesthesia during bypass by ventilating the lungs directly with a weak halothane vapour after the patient had showed obvious signs of being too light.[6] Fig. 2 illustrates a possible course which might be taken by the bronchial blood to account for this peculiar effect. The entry of bronchial arterial blood to the pulmonary capillaries would also be necessary to account for the undesirable effects of active ventilation of the lungs during bypass.

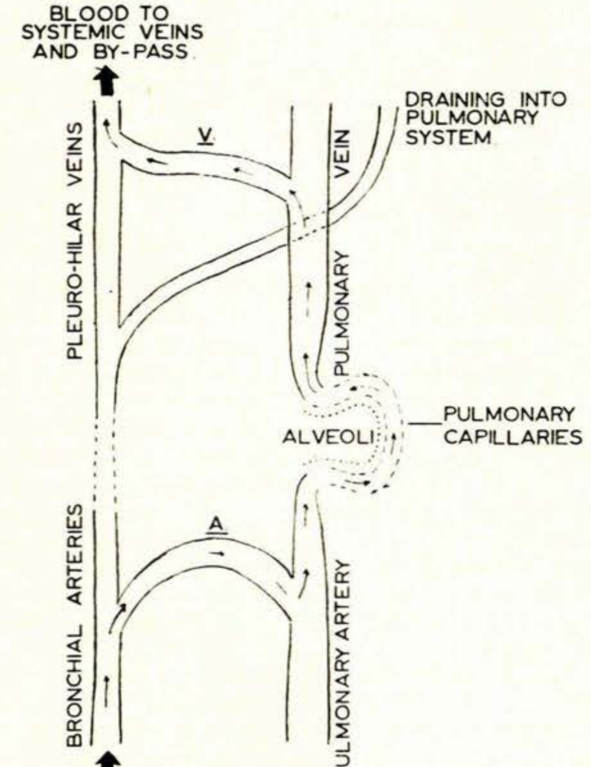

Fig. 2. See text. A = broncho-pulmonary arterial anastomosis. V = broncho-pulmonary venous anastomosis. Small arrows indicate possible paths of the circulation in the lungs.

Metabolic acidosis. Metabolic acidosis during anaesthesia is usually due to inadequate tissue perfusion and is a common complication in operations with cardio-pulmonary bypass. Pump perfusion rates are based on surface area and the original formula used was:

Perfusion Rate (litres/min.) = 1·8 × Surface Area (sq. metres)

Calculated on this basis, perfusion rates were too low and a marked acidosis was the almost invariable outcome. More recently perfusion rates have been increased to 2·3 × Surface Area l./min. with much more satisfactory results. It is also important to maintain the perfusion rate at this level even if blood is lost in passing through capillaries and, if the amount returning to the venous side shows such a loss, blood must be added to the pump circulation.

More recently another factor contributing to acidosis has been introduced with the use of plasma expanders for pump priming. The dextrose solutions employed for this purpose have been found to have a very low pH value (5·0 or even lower). To counteract this, sodium bicarbonate is added to the pump blood in the proportion of 8·5 G for every 1,000 ml. dextrose solution. Throughout the procedure, Astrup readings for pH, pCO_2, standard bicarbonate and base deficit are taken at regular intervals. The development of a metabolic acidosis is indicated by a fall in pH and total bicarbonate; O_2 saturation readings are often omitted and are chiefly of value in congenital cyanotic cases.

3. *Post-bypass Stage*

In many respects the post-bypass stage is the most critical of all, for it is then that it becomes apparent whether or not the heart, on which repairs have been effected, is capable of taking over and maintaining a circulation again.

Rewarming is commenced before the repair has been completed, and it is necessary to restore the temperature to about 37°C before defibrillation is carried out. Before re-starting the heart, the breathing bag is compressed to expel as much as possible of the blood in the lungs into the atria to reduce the risk of air embolism. In cases where the operation has been intraventricular, a catheter is placed in the apex of the ventricle and the patient placed in a head-down position so that air is displaced through the catheter as the ventricle fills with blood. When blood flows freely, the catheter is withdrawn and the opening closed. Penicillin may also be responsible for embolic complications, and the practice of adding massive doses of penicillin to the pump blood has now been discontinued.

Before attempting to re-start the heart, the ligatures round the venous cannulae are loosened so that blood can once more enter the atria, while the pump is kept in action at a reduced output. Under these conditions the circulation is said to be on 'partial bypass', and this is maintained until the heart is capable of maintaining an adequate circulation on its own, when the catheters are removed and the vessel walls closed with purse-string sutures. When the heart has been successfully re-started, deheparinization is carried out by giving 2 units of protamine sulphate for every unit of heparin employed.

At this stage ventilation of the lungs in the normal manner is resumed. If a metabolic acidosis has developed, the neutralization of lactic acid by sodium bicarbonate in the blood leads to increased CO_2 production, which will require some hyperventilation for its removal. Excessive hyperventilation should be avoided, since, once the excess CO_2 has been eliminated, it can do no further good and it is quite possible for a metabolic acidosis and a respiratory alkalosis to coexist. The chief clinical manifestations of a metabolic acidosis are shock and hypotension which cannot be accounted for by other factors, and failure to resume adequate spontaneous breathing after decurarization. Its presence is confirmed by the pH and total bicarbonate readings but it must be remembered that, since the acidosis is mainly due to inadequate tissue perfusion, it may not be truly reflected by the blood picture. For the same reason the treatment, which consists of the intravenous administration of sodium bicarbonate, should be carried out slowly over a considerable period.

Pulmonary ventilation is maintained until the end of the operation, after which the muscle relaxant is reversed. With the resumption of spontaneous breathing there is usually, in uncomplicated cases, evidence of rapidly returning consciousness.

COMPLICATIONS

Cardiac Failure

Not unnaturally this is by far the commonest cause of death associated with this type of surgery. In uncomplicated procedures where the myocardium is not too severely involved, a rapid resumption of effective spontaneous cardiac rhythm may be anticipated when the heart has been re-started and the pump circulation brought to an end but, at the other end of the scale, there are many cases where, as a result of severe and complex pathology, it may be impossible to correct the abnormality adequately, or the diseased organ is unable to survive the severity of the operation. In these circumstances, either the heart cannot be re-started or is unable to provide a sufficient circulation to maintain life and soon fails completely.

Between these two extremes, it often happens that the heart has to be 'weaned' back gradually to normal function after the completion of the operation and may require the assistance of a partial bypass for a considerable time and, in some cases, direct cardiac massage. Such resuscitation requires a much more pharmacological approach than is usually either necessary or desirable in the anaesthetic management of the great majority of surgical patients.

A wide variety of drugs are employed and their actions, and possible dangers, must be fully appreciated. Atropine is used in cases of bradycardia and calcium chloride and strophanthus for increasing the force of systole. Potassium deficiency, and signs of calcium or digitalis intoxication, are usually treated by the administration of potassium chloride. Procaine amide (and more recently pronethalol) have been used for their effect on ventricular tachycardia, while isoproterenol raises the blood pressure in cases of hypotension and may also improve the heart rate in bradycardia which is refractory to atropine. When the myocardium is in fine fibrillation at the end of the operation, defibrillation is greatly facilitated if the condition is first coarsened by the administration of adrenalin. The progress of all this treatment should be controlled by careful monitoring of the ECG, arterial and venous pressures and blood chemistry. It is extremely important to remember that many drugs may be ineffective in the presence of a metabolic acidosis, the incidence and treatment of which is discussed elsewhere.

Respiratory Failure

Inadequate breathing after reversal of the relaxant may be attributable to: (*a*) operative trauma to chest wall, (*b*) some degree of pulmonary collapse, (*c*) pulmonary oedema, or (*d*) metabolic acidosis.

If poor pulmonary ventilation persists it will, in nearly all cases, require respirator treatment. A cuffed endotracheal tube may be used where early improvement is to be expected, but in long-term cases tracheostomy is required. Specific treatment for any contributing causes must, of course, be carried out at the same time.

Metabolic Acidosis

Metabolic acidosis at the end of the bypass stage is usually treated with a sodium bicarbonate drip containing 4·25 - 8·5 G. The solution is diluted and given slowly according to the degree of base deficit.

Embolism

The signs of embolism are convulsions, failure to recover consciousness in spite of an apparently adequate circulation, and localizing signs such as paralyses and dilated or unequal pupils. The commonest causes of embolism are: (*a*) The lodgement of air, which has been trapped in the chambers of the heart in the cerebral vessels, (*b*) penicillin which has been added to the pump blood, and (*c*) detached foreign bodies (e.g. vegetations on valves).

The management of embolism usually involves a prolonged period of respirator ventilation with the patient unconscious and virtually in a vegetable existence. When the condition is due to air or penicillin the ultimate prognosis is fairly good, but cases due to detached foreign bodies usually terminate fatally.

Renal Shut-down

The incidence of this catastrophe has been greatly reduced by the use of mannitol in the pump circulation. It is to be noted, however, that mannitol may cause considerable depression of pulmonary ventilation. This has also been demonstrated on dogs by Nahas *et al.*[7]

Jaundice

Severe, and sometimes fatal, jaundice may follow incompatibilities in the blood used for the pump circulation. Jaundice with a delayed onset, which may develop months later, is not uncommon in cases with tricuspid incompetence and is attributable to hepatic congestion.

POSTOPERATIVE MANAGEMENT

All patients receive individual nursing attention from specially trained personnel, and a fairly high proportion are kept on respirator treatment for varying periods. The intensive monitoring carried out during the operation is continued. This includes:

1. Arterial and venous pressure.
2. Cardiac monitoring by oscilloscope.
3. Rectal temperature.
4. Blood chemistry (pH, pO_2, and total base).

The fluid balance (intake and urine output) is carefully watched. The body temperature should be kept below 100°F and if it shows a tendency to rise above this figure, artificial cooling is resorted to. Active physiotherapy and breathing exercises are instituted as early as possible.

Most of the complications associated with the terminal stages of the operation, such as hypotension, acidosis and embolism, may manifest themselves during the postoperative period and must be carefully watched for. Reactionary haemorrhage is not uncommon and may necessitate reoperation. The anaesthetic management of these cases presents a grave risk as they often suffer from severe respiratory restriction and cardiac tamponade due to massive haemothorax and haemopericardium. In septal defects, obstructive cardiopathies and some valve replacement procedures, portions of the AV bundle may be included in ligatures leading to heart block. This may call for the emergency use of the pacemaker and, in some cases where the danger is known to exist, pacemaker leads may be stitched in at the end of the operation as a precautionary measure.

CONCLUSION

The foregoing account, while far from complete, gives some idea of what is involved in a typical cardio-pulmonary bypass procedure, especially in so far as it affects the work of the anaesthetist. This branch of surgery is still very much in the experimental stage and, no doubt, time will produce many radical changes in approach.

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