MANAGEMENT OF ANAESTHESIA DURING PROFOUND HYPOTHERMIA

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Many centres of cardiac surgery are now using deep hypothermia with extracorporeal circulation. For this, two techniques are available; a pump-oxygenator may be used, with a heat exchanger (Ross, 1960), or alternatively the patient’s lungs may be used to oxygenate the blood, which is then circulated through the pulmonary and systemic vessels by means of two extracorporeal pumps (Drew and Anderson, 1959; Drew, Keen and Benazon, 1959). Working in the Nuffield Department of Surgery in Oxford, we have been using a Gibbon pump-oxygenator and the purpose of this article is to give an account of the procedure that we adopt, with special emphasis on the practical lessons we have learned in connection with anaesthetic management.

THE ADVANTAGES OF DEEP HYPOTHERMIA AND CIRCULATORY ARREST

The principle of lowering the body temperature in order to reduce tissue oxygen requirements is well established. Clinically, the conventional limit to hypothermia has always been 28–29°C, because of the danger of ventricular fibrillation, but if an extracorporeal pumping system is available to maintain the circulation, temporary ventricular fibrillation no longer matters and there is no theoretical limit to the degree of hypothermia which may be induced. If a heat exchanger is incorporated in the pumping circuit, body temperature may be lowered more rapidly and predictably than by any other means.

With profound hypothermia many of the disadvantages of perfusion at normal temperature can be avoided. For example, the performance of exacting operations within the heart is greatly facilitated by cardiac arrest with a completely dry field; the heart stops during profound hypothermia, and this is preferable to the use of drugs to produce cardiac arrest since it is now believed that these may cause myocardial damage (Greenberg, Edmunds and Brown, 1960; Kusunoki et al., 1960). At a temperature of 10–13°C perfusion may be discontinued completely for at least 1 hour without apparent ill effect; once the heart has been emptied of blood the surgeon’s view is then unimpeded and if necessary cannulae may be removed from the heart and great vessels. A sucker is not needed to return blood from the coronary sinus to the pump-oxygenator; with continuous normothermic perfusion this has always been a problem because, apart from interfering with the surgeon’s view, such suckers are responsible for a great deal of haemolysis.

PERFUSION

Much of the early work on extracorporeal circulation was carried out with low rates of perfusion (Sealy, Brown and Young, 1958). This was to some extent unavoidable, because oxygenators large enough to provide high perfusion rates to adult patients are difficult and expensive to manufacture and require large quantities of blood. Nevertheless, experience over the years has shown that although perfusion at low rates of flow may be adequate to maintain life during the period of time required for an intracardiac operation, it is far from ideal from the point of view of tissue metabolism in general: considerable metabolic acidosis results from this type of perfusion and the majority of workers now use pump oxygenators capable of delivering high flow rates to even the largest patients.

An advantage that has been claimed for deep hypothermia is that, because tissue oxygen requirements are reduced, a lower perfusion rate becomes feasible and thus a smaller oxygenator and a smaller volume of blood can be used. This argu-
ment may not be entirely sound, however, since perfusion rate probably makes a considerable difference to the partial pressure of oxygen in the tissues (see below). Also, if a low rate of perfusion is used during cooling, intense vasoconstriction develops and a severe metabolic acidosis still occurs. For these reasons, we now believe that high rates of perfusion are advisable even with the hypothermic technique: with a high flow of blood through the patient's tissues, vasoconstriction is more easily avoided and even after prolonged circulatory arrest metabolic acidosis is slight (Pierucci, Haupt and Templeton, 1960).

Technically, if a well-tried pump-oxygenator and an efficient heat exchanger are available, the problems of perfusion at low temperatures are not greatly different from those of normothermic perfusion. Once a film of blood has been created on the oxygenating screens of the Gibbon machine, pumping must be continuous or else the blood film will break: thus, blood continues to flow round the pump-oxygenator circuit even during the period of complete circulatory arrest for the patient. The practical consequence of this is that the total length of time during which blood is subjected to the effect of the extracorporeal pumps is considerably prolonged; allowing for the period of cooling, the period of circulatory arrest and the period of rewarming, this time may be anything up to 3 hours as compared to an average of about 45 to 60 minutes with normothermic perfusion. However, most extracorporeal pumps in current use cause only very slight amounts of haemolysis even after these longer periods of time.

**OXYGEN TRANSPORT**

A continuous flow of 10 l. of oxygen and 300 ml of carbon dioxide per minute is passed through the oxygenator, so that the contained blood is subjected to a high partial pressure of oxygen. The efficiency of an oxygenator varies in different circumstances but the work of Kirklin, Theye and Patrick (1958) suggests that in the Gibbon oxygenator a blood oxygen tension of 100 to 250 mm Hg is obtained after one passage across the screens, during normothermic perfusion. In practice, the oxygen saturation of the blood leaving the oxygenator varies between 96 and 100 per cent.

When hypothermia is induced, certain additional factors must be taken into consideration. According to Mustafa Oz et al. (1960), with a temperature drop from 38°C to 10°C the viscosity of the blood increases by 55 per cent. This means that unless the extracorporeal pumps are specially calibrated for low temperature work, the actual perfusion flow rate received by the patient will be considerably less than that indicated on the machine gauge. A further problem concerns the solubility of oxygen in blood: this increases as the blood temperature falls, so that if the blood is fully oxygenated at a temperature below that of the body there is a danger that micro-emboli will form. In practice, the temperature of the blood must be reduced, by the heat exchanger, to considerably below that of the patient in order to facilitate cooling; the temperature of the perfused blood, which we now measure by means of a thermocouple incorporated in the circuit, may be as low as 4°C. The danger of micro-emboli is avoided by oxygenating the blood at or above the temperature of the patient and then cooling it by interposing the heat exchanger between the oxygenator and the arterial line.

We are indebted to Dr. R. Marshall for the following theoretical considerations concerning the influence of perfusion flow rate and arterial oxygen saturation on tissue oxygen tension:

Consider the case of an adult patient at a temperature of 20°C. Assume that the blood has an oxygen capacity of 16 vol. per cent, and assume that the body oxygen uptake is 50 ml/min.

*With a perfusion rate of 3 l./min.*

The patient must extract 50 ml oxygen from each 3,000 ml blood, i.e. 5/3 ml oxygen from each 100 ml blood.

\[
\text{A-V oxygen difference} = 1.7 \text{ ml per cent.}
\]

Assuming a blood oxygen tension of 200 mm Hg (arterial), then

\[
\text{Haemoglobin saturation will be 100 per cent.}
\]

Dissolved oxygen (at 20°C) will be 0.9 vol per cent (Bartels and Opitz, 1958).

\[
\text{Venous oxygen saturation} = \frac{16.9-1.7}{16.0} = 95.0 \text{ per cent.}
\]

At 37°C this would represent a venous oxygen tension of 80 mm Hg, but at 20°C the following values would obtain (Severinghaus, 1958):

- At pH 7.4 venous \(P_{O_2}\) = 38 mm Hg
- At pH 7.0 venous \(P_{O_2}\) = 56 mm Hg
- At pH 7.6 venous \(P_{O_2}\) = 30 mm Hg

If the oxygenator performance is such that only 95 per cent arterial saturation is obtained, then
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arterial oxygen tension will be
37.5 mm Hg
dissolved oxygen tension will
be 0.16 vol. per cent

Venous oxygen saturation
\[ \frac{15.36}{1.6} = 86.3 \text{ per cent} \]
thus, at pH 7.4, venous \( P_{O_2} \) = 25 mm Hg
at pH 7.0, venous \( P_{O_2} \) = 37 mm Hg
at pH 7.6, venous \( P_{O_2} \) = 20 mm Hg

With a perfusion rate of 1 l./min,
\[ \text{A-V oxygen difference} = 5.0 \text{ ml per cent.} \]

assumed a blood oxygen tension of 200 mm Hg
(arterial),

venous oxygen saturation
\[ \frac{16.9 - 5.0}{16.0} = 74.4 \text{ per cent.} \]
at 20°C, at pH 7.4, venous \( P_{O_2} \) = 19 mm Hg
at pH 7.0, venous \( P_{O_2} \) = 28 mm Hg
at pH 7.6, venous \( P_{O_2} \) = 15 mm Hg

If the oxygenator performance is such that only
95 per cent arterial saturation is obtained,
at pH 7.4, venous \( P_{O_2} \) = 16 mm Hg
at pH 7.0, venous \( P_{O_2} \) = 23 mm Hg
at pH 7.6, venous \( P_{O_2} \) = 13 mm Hg

The important points to be noted from the
above calculations are firstly, that although venous
oxygen saturations may be high during hypothermic
perfusion, the actual oxygen tension in this
venous blood is remarkably low. Furthermore, a
reduction of the perfusion flow rate from 3 l./min
to 1 l./min would be expected to reduce the
venous oxygen tension by 100 per cent for any
given pH. It would appear that the tendency for
blood pH to fall when low perfusion rates are
employed might offer some measure of protection
to the tissues since their oxygen tension would be
considerably higher than with a pH in the normal
range. Nevertheless, the advantage of a higher
perfusion rate is clear.

TEMPERATURE

A difficulty common to all forms of hypothermia
is vasoconstriction in response to cooling, with
consequent "gradients" of temperature between
different parts of the body. When this occurs, it
is meaningless to speak of the patient's tempera-
ture, since the temperature of each organ may be
different; for example, the reading of an oeso-
ophageal thermometer may give a completely
unrealistic impression of the temperature of the
brain. This difficulty has given rise to much heated
argument as to the "best" site for temperature
measurement during hypothermia.

When inducing hypothermia by means of a
pump oxygenator, vasoconstriction may be pre-
vented by using high perfusion rates and by re-
ducing the temperature of the perfused blood
slowly rather than suddenly: it is most important
to ensure that the blood is at body temperature
when perfusion begins, otherwise the sudden
introduction of cool blood will invariably cause
the vascular bed to constrict at the outset. If
significant temperature gradients are avoided in
this way, a single reliable thermometer placed in
the upper oesophagus is quite adequate.

Cooling to 10°C usually takes place in 30 to
40 minutes. During circulatory arrest for about
1 hour, in an air-conditioned operating theatre,
the patient's temperature may rise by 2 to 3°C.
Rewarming can be accomplished as quickly as
possible and the temperature should be taken up
to at least 36°C before perfusion is discontinued.
Indeed, it is advisable to maintain perfusion for
10 to 15 minutes after normal temperature has
been restored, as otherwise a considerable fall in
body temperature may occur during the conclud-
ing stages of the operation. This is particularly
likely if large volumes of stored blood have to be
transfused: it is disturbing if cardiac arrhyth-
mias are present or if atropine and neostigmine
have to be given.

ANAESTHESIA

Most of the common inhalation agents have been
advocated for extracorporeal circulation work
(Mendelsohn et al., 1957; Patrick, Theye and
Moffitt, 1957; Telford and Keats, 1957; Dawson,
Theye and Kirklin, 1960), and there is probably
little to choose as long as the general principles
of minimum dosage and efficient pulmonary
ventilation are observed (Smith and Engineer,
1960). Facilities must always be available for
aspirating secretions from the trachea and bronchi
and at last one absolutely certain route for the
intravenous administration of fluids and drugs
must be established. Some workers have at-
ttempted to avoid the necessity for using atropine
and neostigmine at the conclusion of the opera-
tion, in case a heart block or other rhythm dis-
turbance should have resulted from the operative
repair. While it is inadvisable to give these drugs
to a hypothermic patient, there seems in practice
to be no disadvantage in using them when the
body temperature has returned to normal; if their effect on the heart rate is particularly feared, they may be "titrated" against each other as described by Gray and Riding (1957). Hypothermia frees the anaesthetist from the responsibility of maintaining oxygenation and unconsciousness during perfusion and allows him to concentrate on assessing the adequacy of perfusion and on the problem of blood volume.

During hypothermia, halothane has been used to maintain vasodilatation (Campkin and Inglis, 1958; Vanderwater et al., 1958; Conn, Allan and Junkin, 1959). The same agent has been employed for extracorporeal circulation cases (Dawson, Theye and Kirklin, 1960), and the resulting vasodilatation enables high perfusion flows to be maintained (Bull, A., personal communication 1960). We have also used halothane in a few cases and as an alternative we have been impressed by the efficacy of trimetaphan injected intravenously at the beginning of perfusion.

During the period of extracorporeal circulation, when the normal pulmonary blood flow is in abeyance, it has been advocated that the lungs should remain slightly distended in order to prevent alveolar collapse (Patrick, Theye and Moffitt, 1957). Some workers have suspected that 100 per cent oxygen may have adverse effects on the respiratory epithelium when the pulmonary circulation is arrested, and the use of helium-oxygen mixtures, or air, has been recommended (Cleland et al., 1958). We have often allowed the lungs to collapse during perfusion; we have not encountered any difficulty in re-inflating them, and no postoperative pulmonary complications have resulted.

PROCEDURE

Before anaesthesia.

Babies are premedicated with atropine alone. Children are premedicated with a rapidly acting rectal thiopentone suspension (Abbott) and atropine. These children have often been subjected to numerous pre-operative investigations, many of which involve anaesthesia, and they are frequently aware of the gravity of the ensuing operation. Thus, apprehension is to be expected, and we make every effort to ensure that they are asleep on arrival in the anaesthetic room. Every child is under the continuous supervision of a doctor from the time that rectal thiopentone is given. Adults are premedicated with pethidine and hyoscine.

The patient is brought to the operating theatre in his bed and he and the bed are weighed together on a bed weighing machine.

Induction of anaesthesia.

In babies, the larynx is sprayed with not more than 0.5 ml of 4 per cent lignocaine and a flexometalic or Oxford endotracheal tube is passed. An oesophageal thermocouple is inserted and a small pack is placed gently in the pharynx: this holds both the thermometer and endotracheal tube in position. Respiration is then controlled using equal volumes of nitrous oxide and oxygen, small doses of d-tubocurarine being given as necessary. A small reservoir bag is used, with a high flow of fresh gases, the arrangement being similar to that described by Rees (1959), except that expired gases are voided through the open limb of a Y-shaped endotracheal connector which is intermittently occluded with the finger (Macintosh, 1955; Parkhouse, 1960).

In children, anaesthesia is induced with an oxygen and cyclopropane or oxygen and halothane mixture, which usually suffices for intubation. For adults a sleep dose of thiopentone is used and intubation is performed under the influence of a muscle relaxant. In both children and adults, anaesthesia is maintained with nitrous oxide and oxygen mixtures with or without the addition of small quantities of halothane, and d-tubocurarine chloride. The patient may be permitted to breathe spontaneously until the operation begins, and this frees the anaesthetist's hands for such duties as setting up of transfusions.

Preparation for perfusion.

When the patient is anaesthetized, he is placed supine on the operating table, with his arms at his sides. E.g.g. and e.e.g. leads are attached, the oesophageal thermocouple is inserted and a cannula is put into a convenient vein in the forearm. This cannula is connected by a length of drip tubing to a three-way tap which remains by the patient's head and provides a convenient route for injections; beyond the tap an additional length of drip tubing leads to the drip chamber and transfusion bottle. In babies a length of polythene tubing is inserted into a suitable vein by cut-down.
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Diagram illustrating arrangement of patient and monitoring equipment during profound hypothermia with extracorporeal circulation. Note spring balance for measuring the amount of blood given from plastic bags.

After preparation of the skin the chest and both groins remain exposed. In children and adults the right femoral artery is isolated ready for perfusion. In babies, whose vessels are small, both femoral arteries are isolated so that later two cannulae may be inserted to ensure adequate flow rates. A catheter is inserted through the left saphenous vein, at the groin, into the inferior vena cava and connected to a pressure recording head. This venous pressure, together with the e.c.g. and e.e.g are displayed on an oscillograph screen in the recording room adjacent to the theatre (fig. 1). This screen is clearly visible to the anaesthetist throughout the operation through an intervening glass panel.

The surgeon exposes the heart through a median sternotomy, and heparin is administered intravenously in a dose of 3 mg/kg body weight. After allowing 1½ minutes for the heparin to become effective, cannulae are placed in the femoral artery and the right atrium and these are connected to the pump-oxygenator. A check is made on blood loss at this stage, to ensure that replacement is adequate before perfusion begins.

During perfusion.
Extracorporeal circulation begins at 37°C, care being taken to ensure that the blood in the pump-oxygenator is at this temperature. The perfusion flow rate is calculated on the basis of 2.3 l./sq.m/min, this being the accepted “high flow” requirement. When this flow is given from the outset, with blood at body temperature, vasoconstriction can usually be avoided. If the flow rate tends to fall and signs of vasoconstriction appear a single injection of 25 to 50 mg of trimetaphan is given intravenously. By maintaining vasodilatation, and by adding blood from
the pump-oxygenator reservoir to compensate for the increase in vascular capacity due to paralysis of vasomotor tone at low temperature (Mustafa Oz et al., 1960), the calculated flow is nearly always exceeded even during hypothermia. Cooling begins when the maximum flow rate has been attained.

Ventricular fibrillation often occurs between 20°C and 27°C, although the rhythm may not alter until asystole occurs at about 20°C. At about 10°C the arterial line is clamped, the venae cavae are snared and the heart is sucked dry. The heart is then opened and the operation is performed during a period of complete circulatory arrest.

When the intracardiac operation is completed, perfusion recommences, using cold blood which is gradually warmed by raising the temperature of the heat exchanger to 42°C. The heart soon begins to contract and, if the ventricle is fibrillating, defibrillation is carried out at 28-29°C.

At 35-36°C the pump output is gradually lowered and the heart is allowed to take over for itself. When it is beating strongly and the arterial pressure is adequate, by which time the body temperature has usually been normal for 10 to 15 minutes, perfusion is stopped.

At the beginning of perfusion, anaesthesia is very light; minimum doses of drugs are used and intravenous analgesics are avoided since hypothermia delays their metabolism and excretion. When the patient's temperature has fallen below 28°C, no further anaesthetic is required. Gentle inflation of the lungs with oxygen is maintained until ventricular fibrillation or asystole occurs: this continued inflation tends to reduce the incidence of "bucking". The lungs are then left to collapse and the gas flow is turned off. When warming begins the lungs are again gently inflated to ensure that there will be no areas of atelectasis at the time perfusion is discontinued. Only oxygen is administered until movements of the patient make it necessary to add nitrous oxide.

After perfusion.

The residual effects of heparin are neutralized by the intravenous injection of Polybrene. Initially this drug is given in the same dosage (in mg) as the original quantity of heparin. A blood sample is then withdrawn and a heparin titration is carried out in the haematology laboratory: if this test reveals that some heparin remains un-neutralized, a further injection of Polybrene is given.

The perfusion cannulae are removed, haemostasis is secured and the chest is closed with a drainage tube connected to a suction bottle.

Many of our patients receive digitalis preoperatively, and after perfusion a rapidly acting digitalis preparation is frequently administered: for this purpose intravenous Cedilanid (Lanatoside C) is injected intravenously in small divided doses. Also, 50 to 100 mg of hydrocortisone are often given intravenously, firstly to safeguard against the development of an adrenal exhaustion syndrome, which has been described under profound hypothermia, and secondly because cortisone is known to restore the bleeding time to normal in cases in which it is prolonged preoperatively without discoverable cause (Sharp, personal communication, 1961).

During closure of the superficial layers of the wound spontaneous breathing recommences, and atropine and neostigmine are given as necessary. A bronchoscopy is performed after removal of the endotracheal tube, in case any secretions require to be aspirated from the bronchial tree; a radiograph of the chest is then taken before the patient leaves the operating theatre. When the patient's condition is satisfactory, he is transferred to his bed and reweighed. He is then returned to the ward with a blood drip running and the femoral venous catheter still in place. The venous pressure and e.c.g. are continuously recorded on an oscillograph screen during the early postoperative period.

**MONITORING**

In common with many other workers, we are convinced of the paramount importance of clinical observation of the patient. The e.e.g., e.c.g., and other measurements all have their place as supplementary indications of progress but they can never give as much information as careful study of the patient as a whole. It is important to note the skin colour, the arteriocapillary refill time and the appearance and behaviour of the heart and venae cavae: all of these give a good indication of the adequacy of perfusion and oxygenation. Inspection of the retinal vessels is easy when the pupils are widely dilated (as they are when trime-taphan is given) and the condition of these vessels gives some indication of the state of cere-
bral blood flow (Gerbode, Osborn and Johnston, 1960). Of the ancillary methods of monitoring, the most useful are the blood pressure, the central venous pressure, and the perfusion flow rate which is read from a precalibrated dial on the machine.

**Blood pressure.**

In one of our cases an extensive deep venous thrombosis occurred in the forearm following use of a sphygmomanometer cuff. Since this incident we have not used a cuff during profound hypothermia with circulatory arrest. During perfusion, pressure in the tubing between the arterial pump and the femoral artery (the arterial line) is measured and a table is available showing the pressure drop across arterial cannulae of various diameters at different flow rates: the mean arterial pressure in the patient's body may thus be determined by subtraction. This mean pressure usually remains at about pre-operative level. After perfusion the arterial pressure is measured directly from a catheter in the femoral artery; it is at this stage, until the conclusion of surgery, that the estimation of arterial pressure is most valuable.

**Central venous pressure.**

This is the most important single index of the body blood volume. During perfusion it is kept at pre-perfusion level by addition of blood from the machine reservoir when necessary. Immediately after perfusion the central venous pressure is taken as the principal guide to the adequacy of transfusion: if the central venous pressure is normal and the arterial pressure is not unduly low, the blood volume is regarded as satisfactory irrespective of the results of blood balance calculations. We consider this to be an important point; the precise measurement of the volumes of blood lost and replaced is open to many inaccuracies (see below), particularly when very large quantities of blood are involved, and in our experience it is much better to be guided by the venous pressure than by hasty calculations.

**The electroencephalogram.**

The changes occurring during deep hypothermia have been described by Benazon (1960). In our cases, return to a normal e.e.g. pattern has not always been immediate after rewarming of the patient. Sudden changes in the e.e.g. pattern are occasionally of value in diagnosing gross circulatory inadequacy, for example, as a result of kinking of the perfusion lines or great vessels but on the whole the e.e.g. gives little information that cannot be elicited by other means.

**The electrocardiogram.**

The action of the heart is best observed directly, but the e.c.g. is useful in the precise diagnosis of rhythm disturbances: for this purpose lead II is employed. Varying degrees of heart block may occur after suture of the ventricular septum; such damage to the conducting mechanism may cause temporary block, due to oedema, or permanent atrioventricular dissociation. Other arrhythmias are common during rewarming. Many rhythm disturbances disappear with adequate rewarming and replacement of lost blood but the use of a pacemaker or isoproterenol may be necessary in heart block. In the post-perfusion and immediate postoperative periods, the e.c.g. is essential for the detection of rhythm changes, for the control of digitalization and for the treatment of residual heart block.

**Blood chemistry.**

The pH of the blood is measured before, during and after perfusion. With high perfusion rates we have found that the blood pH rarely falls below 7.3, even after more than an hour of circulatory arrest. It must be made clear, however, that these pH measurements have been made at normal body temperature: if corrected for profound hypothermia they would rise by approximately 0.2 but the significance of blood pH and other biochemical constants at low temperatures is not precisely known.

**BLOOD BALANCE**

**Measurement of loss.**

As described above, the patient is weighed before and after operation, allowance being made for the weight of dressings and the volume of urine removed if the patient is catheterized at the end of the operation. Throughout the operation, swabs are weighed: the majority of these swabs are used dry but if saline or other solutions are put out by the nursing staff the volumes of these are noted. All blood removed by suction, from the thorax and from inside the heart, is led into a graduated cylindrical flask at the anaesthetist's eye level: this flask can be drained periodic-
ally into a graduated Winchester jar (fig. 2). At
the end of the operation, when a final blood
balance has been made, suction is transferred to
the graduated chest drainage bottle (also of
cylindrical shape) with which the patient returns
to the ward. In addition, blood volume estimations
have been made in some cases by means of red
cells tagged with radioactive chromium.

Sources of error.
Blood may be lost on to the surgeon's gown, the
sterile towels and the operating theatre floor;
saline and heparin-saline solutions may be lost in
the same way. During connection and withdrawal
of the cannulae, blood may be lost from the patient
or from the pump-oxygenator. During perfusion,
oedema fluid may be returned from the patient
to the pump; there may be some leakage from
connections, and with a large pump-oxygenator,
holding several litres of blood, it is difficult to be
accurate to within 100 ml in assessing the final
pump blood volume.

Even if blood loss is measured fairly accurately,
it does not always follow that the same quantity
should be replaced. During deep hypothermia
vasomotor tone is lost and the intravascular
capacity of the body increases (Mustafa Oz, et al,
1960); repair of a complex intracardiac defect may
bring about a sudden and radical change in
haemodynamics. During rewarming, and after
recovery of the patient, it is sometimes apparent
that although calculations suggest that blood re-
placement has been adequate the patient is
clinically undertransfused. In these circum-
stances supplementary transfusions are given from
the pump-oxygenator before the femoral cannula
is removed until the tone of the heart, the central
venous pressure and the femoral arterial pressure
are satisfactory.

When the heart has resumed control of the
circulation effectively after perfusion, blood loss
is made good as it occurs by the intravenous route.
This is a period of the operation during which
constant vigilance is essential, since until cannulae
are removed and the effects of heparin are fully
counteracted blood loss may be very considerable
and this loss may persist in the early post-
operative period. For this reason postoperative
weighing of the patient and return to the ward
should be as expeditious as possible: reliance must
not be placed on simple underwater seal drain-
age because unless suction is applied concealed
blood loss may occur within the chest.

Varieties of blood.
The blood used for priming the pump-
oxygenator is collected not more than two days
before the operation, and is prevented from clot-
ting by admixture with EDTA (ethylene-diamine-
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tetra-acetic acid) which removes free calcium ions. Before use, heparin and calcium ions are added. Full blood studies are carried out pre-operatively on each patient and, if any coagulation defect is revealed, only fresh heparinized blood is used. For the replacement of blood loss after perfusion and in the early postoperative period, we use fresh blood collected anaerobically into sealed plastic bags in order to prevent loss of platelets. These bags can be used with ordinary plastic drip tubing and a Martin's pump, and the amount that has been transfused from any given bag can be measured by hooking the bag to a small spring balance which hangs from the drip stand (fig. 1). Stored citrated blood of the appropriate group is also crossmatched and made available: this blood is used, if necessary, to replace losses before perfusion begins and it also forms a useful reserve for the post-perfusion period in case blood loss is very large. Concentrated solutions of platelets and fibrinogen are available in case haematological studies at the end of perfusion indicate that they should be used.

DISCUSSION

After the induction of anaesthesia, while breathing an oxygen-rich mixture, these patients appear pink and vasodilated, with a normal or slightly reduced blood pressure. In patients with high pulmonary vascular resistance, and equally balanced left-to-right and right-to-left shunting, the institution of controlled ventilation may result in a sudden fall of arterial oxygen saturation, with bradycardia and e.c.g. changes indicative of myocardial ischaemia. The anaesthetist must be aware of this possibility.

When perfusion begins anaesthesia is very light and movements of the limbs and eyes often occur. When the perfusion flow rate has been adjusted to the maximum attainable, and particularly if trimetaphan has been given, the skin looks pink and vasodilated and the arteriocapillary refill is brisk. The clinical picture remains the same despite the fall in body temperature until the circulation is arrested. The pupils dilate widely if trimetaphan is given and remain dilated during circulatory arrest and rewarming. When perfusion is discontinued for performance of the intracardiac operation, blood gradually drains out of the dilated vessels of the face and this takes on a white-blue mottled appearance resembling post-mortem lividity. As soon as perfusion recommences the still dilated vessels fill with oxygenated blood and the face is immediately suffused with a bright pink colour which persists throughout rewarming.

After perfusion the restoration of a clinically adequate blood volume and complete re-expansion of the lungs are essential. If the surgical repair has been successful there should be no untoward events during closure of the chest. If perfusion has been adequate, if there has been no period of prolonged hypotension, and if the temperature is restored to normal, the patient should recover consciousness immediately after extubation. The incidence of respiratory complications has been no higher than after normothermic perfusion and there has been a notable absence of intrabronchial secretion at the end of the operation.

In this series patients have been subjected to periods of up to 75 minutes of circulatory arrest, at temperatures between 10°C and 13°C; there have been no apparent ill effects, and postoperative electroencephalograms have shown no change.

Other centres have reported postoperative psychoses and other cerebral complications after deep hypothermia with circulatory arrest (Björk and Hultquist, 1960). Indeed, some experienced workers now limit the period of circulatory occlusion to not more than 45 minutes. In one of our cases, a girl of 19 whose personality was somewhat unstable, an acute psychosis developed in the week following operation but this quickly recovered and appeared to be no different from the mental disturbances which are occasionally reported after other forms of surgery. With the exception of this case we have not seen cerebral complications. At the moment the causes of cerebral damage during profound hypothermia with circulatory occlusion are unknown, although the occurrence of capillary thromboses has been suggested (Björk and Hultquist, 1960). There is also some evidence that perfusion of the normothermic brain with very cold blood, or alternatively, perfusion of the cold brain with warm blood at the commencement of rewarming, may have deleterious effects (Drew, 1961). As mentioned above, we have taken care in our cases to ensure that perfusion is started with blood at body temperature and that, at the commencement of
rewarming, perfusion begins with blood at 10–12°C.

As far as we are aware, the use of trimetaphan for extracorporeal circulation cases has not been described before. In our experience it certainly appears to help in maintaining high perfusion flow rates and, if the total “circulating blood volume” (that is the volume in the pump-oxygenator, the arterial and venous lines, and the patient) is appropriately adjusted, the mean arterial pressure does not fall significantly. The chief disadvantage of trimetaphan is that the duration of its action is uncertain: we have not experienced any additional difficulty in adjusting the patient’s blood volume after perfusion since using trimetaphan but the persistence of wide dilatation of the pupils in the early postoperative period is disconcerting to the uninitiated and destructive of a useful physical sign. The advantage of using halothane to ensure vasodilatation is that it can be washed out of the body through the lungs, or indeed, through the oxygenator, so that the duration of its action is more controllable; but against this must be weighed the danger of myocardial depression.

With the above technique 37 patients have now been operated on at 20°C or below; all but 3 of these cases have been subjected to periods of complete circulatory arrest, ranging from less than 45 minutes (13 cases) to over an hour (11 cases). The minimum oesophageal temperature has been below 15°C in 29 cases, and below 12°C in 12 cases.

With increasing experience of the technique we are now using these lower temperatures routinely. We have also operated on 1 case of atrial septal defect at 25°C and 1 case of pulmonary stenosis at 27°C. Fatalities have occurred but most of these have resulted from attempts to repair extremely complex congenital defects; for example, there have been 4 cases of transposition of the great vessels, all of which died. On the other hand, 4 of our 5 cases of tetralogy of Fallot and all of our 7 uncomplicated cases of ventricular septal defect have survived. There has been no mortality or morbidity attributable to the anaesthesia, or to the technique of profound hypothermia with circulatory occlusion. Full details of the series will be published by the Nuffield Department of Surgery (Gunning, in preparation).

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REFERENCES


THE FIRST EUROPEAN CONGRESS OF ANESTHESIOLOGY

will be organized by the Austrian Society of Anesthesiology in Vienna from September 3 to 7, 1962.

The former Imperial Palace will serve as the meeting place, where there will be a Scientific Congress as well as a Postgraduate Medical Training Course.

English, French and German will be the working languages. Provision will be made for simultaneous interpretation.

The main subjects of the Scientific Congress are:

1. Watch Stations and Special Care Units.
2. Old Patients and Anaesthesia.
4. Free Papers (10 to 15 minutes) in limited numbers.

This programme will be supplemented by a series of Symposia on specific problems of anaesthesia and related questions. Participants who wish to organize a Symposium (about 90 to 120 minutes) should contact the Scientific Secretary—who will also furnish any other information in relation to the scientific programme—by September 30, 1961, at the very latest. These participants should indicate, at the same time, the subject of their Symposium as well as the names of the intended discussants (address: Dr. Karl Steinbereithner, Postgraduate Medical School, 4 Alserstrasse, Vienna IX).

A preliminary programme will be circulated in the autumn of 1961. It will include registration forms. For information kindly apply to the Secretary General, Dr. Rudolf Kucher, address as above.