HYPOTHERMIA
A Review of the Present Position
By H. C. Churchill-Davidson, M.D., D.A.
Will Edmonds Research Fellow of the Royal College of Physicians

Since the early days of surgery, operations on the heart and great vessels have been hampered by the difficulty of creating a 'bloodless field' or, as it is sometimes described, 'a dry heart.' Arrest of the circulation, even for short periods, is known to cause serious damage to the tissues. Many great surgeons, not least amongst whom ranks Sir James Paget, have considered that operations within the chambers of the heart were outside the domain of possible surgery. If it were possible to overcome these difficulties, the method used might prove of value during more extensive operations in general surgery.

During the past 25 years great strides have been made not only in the repair of congenital cardiac abnormalities and stenosis of the mitral and aortic valves, but also in the surgical removal of such lesions as aneurysms of the aorta.

At the present time nearly all operations within the heart are performed by a sense of touch alone. If further advances in this field are to be made a way must be found whereby a chamber of the heart can be opened, the lesion exposed and repaired, whilst the circulation to the remainder of the body is maintained by some other means.

There are two possible lines of approach to this problem. First, the whole or part of the circulation may be taken over by a mechanical pump-oxygenator (Dennis et al., 1951; Miller et al., 1951; Björk, 1948; Melrose, 1953). Such machines are, as yet, at an early stage of their development. Secondly, the metabolism of the body can be so reduced that the cells of the various organs can withstand prolonged ischaemia. This is achieved by a reduction in body temperature and is termed 'hypothermia.'

Historical Note

In 1940 Laurence Smith and Temple Fay reported their observations on the use of cold in the treatment of cancer patients. The patients were given a small dose of barbiturate, cooled by packing in ice and then maintained between 75° to 90° for four to five days, after which they were rewarmed to normal body temperature. The rationale of this treatment was based on their finding that cold led to signs of retrogression and degeneration of the malignant cells—similar to that seen after radiotherapy. Though they reported some improvement in their patients, the main benefit apparently lay in the relief of pain in cases with intractable carcinoma.

In 1951 Laufman reported the case of a negro woman who was admitted to hospital in 'cold coma.' Her rectal temperature 45 minutes after admission was 18° C., respirations three to five per minute and pulse rate 12 to 20 per minute. On rewarming the patient regained consciousness around 30° C., and apart from severe frostbite of hands and feet (requiring amputation) she made satisfactory recovery. A history taken from the patient's father revealed that she had been drinking alcohol more or less steadily for some nine hours prior to the time she lost consciousness. Dressed in only light clothing she probably lay exposed to temperatures below freezing point for 11 hours. There is little doubt, in the light of present knowledge, that without the anaesthetic properties of alcohol this patient would never have survived such exposure.

Bigelow et al. (1950) were the first to describe the possibilities of a reduced body temperature in cardiac surgery. They recalled that at normal body temperatures (38° C.) a dog will survive exclusion of the heart from the circulation for periods of five to nine minutes (Templeton and Gibbon, 1949). Using hypothermia (20° C.) they were able to demonstrate that dogs would tolerate 15 minutes of circulatory arrest. However, only 15 per cent. of their series actually recovered. Cookson et al. (1952) using similar operative procedure obtained a mortality of only 17 per cent. in 27 animals in whom the cavae were occluded for 12 minutes at 26° C. The different degrees of hypothermia chosen in these two studies must have been one of the reasons for the increased mortality in Bigelow's series, for it has been shown that in a series of 20 dogs cooled to 28° to 26° C. for half an hour without any surgery and then rewarmed again there was no mortality, whereas in
another series cooled under identical conditions to 24° to 22° the mortality was 25 per cent. (Churchill-Davidson et al., 1953).

Throughout the development of this work it has become increasingly clear that whereas all the other organs in the body may suffer no damage from hypothermia, the heart muscle becomes more ‘irritable’ and the tendency to develop spontaneous ventricular fibrillation becomes greater the lower the body temperature falls (Churchill-Davidson et al., 1953).

Renewed interest in the possible application of hypothermia to man followed the publication of details of closure of an atrial septal defect under direct vision by Lewis and Tauffig (1953). Since then Swan et al. have used hypothermia (ranging from 21.5° to 28° C.) during cardiac surgery in 15 human patients. In 13 of these patients the circulation was occluded for periods ranging from 2 to 8½ minutes, during which a stenotic pulmonary valve was excised (seven cases) or an inter-atrial septal defect was repaired (five cases) under direct vision. In the remaining two cases it was not necessary to interrupt the circulation. There was only one operative death (due to ventricular fibrillation) in this series.

**Physiology of Hypothermia**

*Blood Pressure, Pulse and Respiration Rate*

As the body temperature falls changes in blood pressure, pulse and respiration rate occur in direct relation to the drop in temperature. Fig. 1 shows a typical example of the changes that take place in an animal during surface cooling. On rewarming these changes should represent the mirror image of the stage of cooling. As the temperature falls so the pulse slows, the respiration becomes steadily reduced in volume and rate until finally it ceases somewhere between 28° C. and 22° C., depending on the depth of anaesthesia used; the blood pressure declines slowly at first but below 30° C. the fall becomes more rapid.

*Metabolic Rate*

One of the great difficulties of obtaining accurate values for the amount of oxygen uptake per minute during hypothermia is the narrow margin that exists between respiratory depression from too deep anaesthesia on the one hand and shivering due to too light anaesthesia on the other. Bigelow et al. (1950) in a small series of animals concluded that the fall in oxygen consumption was linear. More recently Lynn et al. (1954), using totally paralyzed and anaesthetized animals on controlled respiration, have confirmed this finding and have suggested that temperatures between 15° C. to 10° C. should be reached if the optimum benefits of metabolic depression from body cooling are to be obtained. Nevertheless, part at least of the uptake of oxygen at such low temperatures must be due to an increase in the amount dissolved in the plasma, for at a body temperature of 20° C. in dogs approximately 32 per cent. more oxygen is physically dissolved in the blood (Penrod, 1951).

![Figure 1](http://pmj.bmj.com/)

**FIG. 1.**—This illustrates the mean changes in body temperature, blood pressure, pulse and respiration rate and oxygen consumption in a series of 20 dogs cooled by partial immersion in water to 24° C. for 30 minutes and then rewarmed. (Reproduced by courtesy of 'The Lancet')
Oxygen Dissociation

As blood cools both in vitro and in vivo the oxygen dissociation curve shifts to the left, thus making it increasingly difficult for the tissues to take up oxygen at low temperatures (Fig. 2). However, the absence of any evidence of an oxygen debt in the tissues suggests that this shift must be counter-balanced by a depression of tissue metabolism. It may be argued that a high carbon dioxide content of the blood would be beneficial in that it would tend to shift the dissociation curve towards the right, but recent work has suggested that the converse may be true (Swan et al., 1953; Lynn et al., 1954).

Acid-Base Balance

Swan et al. (1953) found a relationship between the carbon dioxide content of the blood and the incidence of ventricular fibrillation. If the carbon dioxide concentrations were kept low during hypothermia by hyperventilation then the incidence of cardiac arrhythmias was reduced. They concluded, like Rosenhain and Penrod (1951), that it was not the carbon dioxide per se which caused the arrhythmia but rather its effect on the pH.

On the other hand, Lange, Weiner and Gold (1949), working with rabbits, found that electrocardiographic changes suggestive of anoxia would revert to normal if the oxygen dissociation was increased by acidification of the blood or if the amount of oxygen physically dissolved in the plasma was raised by respiring the animals under pressure with oxygen. They concluded that the cardiac irregularities seen during hypothermia were the result of anoxia or anoxaemia of the cardiac muscle. Penrod (1951) has shown that the arterio-venous oxygen difference of the blood in the coronary circulation is unchanged by the fall in body temperature, but the problem of whether the coronary flow is adequate for the amount of work required of the cardiac muscle still remains.

Blood Coagulation

During surgery increased oozing may be noticed but usually the bleeding is no greater than normal, though two cases of persistent haemorrhage during hypothermia have already been reported following the use of chlorpromazine (Dundee et al., 1953). The necessity for observing meticulous care in arresting all bleeding points is similar to that found with other hypotensive techniques.

Electrolyte Changes

The significance of the changes in the electrolyte balance during cooling is not yet sufficiently understood. In animals respiring spontaneously the potassium level rises whereas during hyperventilation it falls (Swan et al., 1953). Magnesium and sodium concentrations fall.

Methods of Lowering the Body Temperature in Man

Exposure to cold in the conscious subject results in a reflex peripheral vasoconstriction in an attempt to prevent a fall in body temperature. If the cold environment persists the body will start to cool. When the body temperature has fallen about 0.5°C the shivering reflex is excited and vigorous muscle tremors take place throughout the body, resulting in increased carbohydrate metabolism and heat production. Further exposure only leads to increased attempts on the part of the body to make good the lost heat, so that tremendous strain is thrown on the circulation until finally the victim succumbs to exhaustion and cardiac failure.

In the anaesthetized subject, provided the depth of anaesthesia is great enough to control shivering, the body temperature falls until ultimately it takes on the temperature of the environment. There are many factors which influence the environmental temperature in a patient undergoing an operation; notably the amount of clothing or blankets covering the patient, the surface area exposed which includes the site and extent of the operative procedure and the amount of heat given off by radiation from the heating lamps.

Chlorpromazine and Hypothermia

In recent years a drug of the phenothiazine group—chlorpromazine—has achieved great prominence, particularly on the Continent, as a method of lowering the body temperature. The site of action of this drug was at first suggested to be upon the peripheral autonomic ganglia (Courvoisier et al., 1953; Huguenard, 1953), but more recently the drug has been supposed to act mainly by a direct depression of the thermo-regulating centre in the hypothalamus (Dundee et al., 1953).

In most cases chlorpromazine (50 mg.) is given intravenously in combination with promazine (50 mg.) and pethidine (100 mg.), the whole volume being injected intermittently over a period of about 30 to 90 minutes. As this mixture is very irritant to the vessel walls it is always advisable to administer it well diluted. During the period of injection the blood pressure usually falls and the pulse rate rises, particularly in elderly subjects, so that rates of 120 to 130 may be attained. At first the patient passes into a deep slumber, often snoring peacefully, but on being roused will speak and then lapse into sleep again. Later, as the
degree of narcosis increases, the body temperature will fall if the environmental temperature is reduced. Usually the degree of reflex suppression with these drugs alone is inadequate for even minor surgical procedures and it is necessary to supplement the narcosis with other anaesthetic mixtures. As yet, it is too early to assess whether this new combination of drugs holds any advantage over the more conventional methods of anaesthesia.

There remains to consider, therefore, the possible ways in which cooling may be brought about in man.

**Surface Cooling.** In the literature surface cooling has figured most prominently and there are many combinations of this technique that may be used. The anaesthetized patient can either be immersed in a bath of cold water, wrapped in a refrigerated blanket or cooled in a draught of cold air. All are effective, but the method selected should be governed by simplicity and the means available.

**Blood Cooling.** The creation of an artificial arteriovenous shunt using a long length of polythene tubing has been successfully used to produce direct cooling of the blood (Delorme, 1952). A silver cannula is tied into the femoral artery and the blood passes through a long length of polythene tubing and is returned to the body via the femoral vein. The exterior of the tubing is then immersed in cold water or in a refrigerated circuit so that the blood cools in its passage from artery to vein. This technique has three possible disadvantages, namely the interference with a main artery, the creation of an arteriovenous fistula and an increased haemolysis due to passage of the blood through an artificial channel. It is claimed, however, that this technique produces more even cooling of the vital organs than is obtained with surface cooling.

**Management of the Hypothermic Patient Cooling**

The time taken to cool a patient by the surface method depends largely on the temperature gradient between the patient’s skin and his environment. The physical build of the patient also affects the speed of cooling, for fat subjects with good insulation require longer than their more lean counterparts with a large bulk of muscle tissue near the surface. There is, however, no reason to believe that rapid cooling has any advantage over slow cooling; indeed it may be argued that a slow but steady fall in temperature is more easily controllable.

A point of particular importance is that the patient should be placed in the position required for the operation before cooling is commenced because the hypothermic patient tolerates any movement badly.

The greater part of the fall in body temperature can usually be arranged to take place during the operation for the maximum fall is not often required until a late stage. Furthermore, it is easier to cool a patient with the thorax or abdomen open as the heat loss is greater; the skilful use of cold packs around the aorta and great vessels greatly facilitates the cooling. It is important that all direct aids to cooling should be removed before the body temperature reaches the desired level as a further fall (depending on the rate of cooling) of at least 2° C. must be anticipated.

Any case in which hypothermia is used should have a continuous electrocardiographic record available, as the onset of cardiac arrhythmias is a sober warning of the imminent danger of spontaneous ventricular fibrillation. The occurrence of arrhythmias in a patient without surgical manipulation of the heart is a clear indication that the temperature is too low and immediate steps should be taken to bring about rewarming.

**Intravenous Infusion**

During hypothermia renal function is progressively reduced as the temperature falls (Miles and Churchill-Davidson, 1954) and so also is the general metabolism. If large quantities of saline or glucose are given intravenously they must necessarily swell the extracellular fluid volume. It is advisable, therefore, to limit the fluid intake during operation and preferably to use half-strength solutions. If a transfusion is required it is important that the temperature of the transfused solution should be approximately that of the patient otherwise, following a period of rapid transfusion, the patient’s temperature may alter by as much as 2° to 3° C. in a few minutes.

**Rewarming**

There is no evidence available at present that there is any advantage in rapid rewarming. Provided it is certain that the patient’s temperature is actually rising a return to normal body temperature may be allowed to occur over 12 to 24 hours. In most cases as the effects of the anaesthesia wear off the patient’s temperature starts to climb rapidly, but it is inadvisable to allow shivering to occur as this must necessarily throw an extra burden on the circulation.

A satisfactory method is to nurse the patient in blankets and over these to place a large electric blanket which is again covered by yet another blanket. The danger of small electric pads and hot water bottles is the very real risk of producing widespread burns, for the skin of these patients is
particularly sensitive to heat. It is advisable to allow even a well-covered water bottle that is hotter than 42°C. to come in contact with the skin.

Complications of Hypothermia

Ventricular fibrillation and cardiac arrhythmias are the outstanding complications of a reduced body temperature. The risk is greater in adults than in the young, and furthermore, the presence of a damaged myocardium probably increases the danger. Not only is ventricular fibrillation more easily induced the lower the temperature falls, but it becomes more difficult to reverse (Churchill-Davidson et al., 1953).

Haemorrhage may follow the increased bleeding time, but if meticulous care is taken all possible bleeding points this complication can largely be avoided.

Hypotension. Prolonged and progressive hypotension leading to a 'failure to rewar' has been described (Huguenard, 1953: Preston and Wishart, 1954). It is said to be common in the older age group.

Pulmonary Complications. In the experimental animal the incidence of pulmonary collapse and oedema increases if deep hypothermia is used. French workers, however, have claimed that hypothermia reduces the incidence in man. Burns may follow the injudicious application of a source of heat to the cold skin.

Possible Indications for the Use of Hypothermia

At the present time there is no evidence available that patients under hypothermia suffer less from the reactions of stress than during other forms of anaesthesia. In fact, it may be that the induction of cooling itself is yet another form of trauma to the patient. As the risks of hypothermia are certainly great this method of anaesthesia should be reserved for those cases in which it is intended to interrupt the circulation to the vital organs for a variable period of time. The repair of aneurysms of the arch or upper part of the descending aorta are obvious choices (Rob and Eastcott, 1954). In cardiac surgery it offers an extension of time for performing operations under direct vision, but at the same time there is an increased risk of ventricular fibrillation. Means must therefore be found whereby this incidence is reduced to that at normal temperatures.

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