immersing a child with altered haemodynamics in a hot bath immediately after a long and sometimes difficult thoracotomy is not wise. There was also the question of delay and mess in the theatre prior to operation, extra handling of the patient, and extra movement of the attendants, such factors being apt to increase the risks of infection, prolong the duration of anaesthesia, and disturb the normal theatre routine.

The use of extracorporeal blood-stream cooling (Ross, 1954, 1956; Brock, 1956) must be restricted to patients undergoing bilateral or right thoracotomy. The blood is subject to the effects of pumping and also to very cold temperatures in the plastic tubing coil; further, this tubing passes into the actively contracting heart, where it may remain for several hours, including the time when the circulation is occluded and the surgeon is repairing cardiac defects. This must represent a certain hazard, and is a major surgical procedure in itself. Also it introduces the possibility of trauma to the heart or great vessels, and might possibly distract the surgeon or interfere with his movements. The tubing can, of course, be disconnected and then reinserted for rewarming purposes, but this means extra handling of an overworked and irritable myocardium. In addition, there must be some risk of haemolysis or thrombosis of the blood in the extracorporeal circuit.

There are also mechanical problems such as flaws in the tubing, kinking during the pumping, inadequate venous return, and so on, any one of which could be serious if it occurred. Rewarming must be initiated and reach a certain stage before the heart can be closed and the operation completed; this adds further to the delay, exposure, and handling of the heart.

In general it will be found that in our method the rate of cooling and rewarming is a little slower than the blood-stream cooling recommended and described by Ross (1954, 1956) and Brock (1956).

The advantages claimed for the method described are as follows: (1) There is no overall delay, since the operation can be started as soon as cooling has been initiated. (2) The procedure is extremely effective and controllable. Cooling and rewarming are achieved at a satisfactory rate, so that the desired temperature is reached by the time the surgeon requires it and adequate rewarming has been established by the time the operation has been completed. (3) No additional surgery is necessary to effect cooling, and it can be employed for any operative procedure for which it would seem to be indicated without necessarily opening the right chest or the pericardium. (4) It is not necessary to begin cooling prior to opening the chest, a decision for or against hypothermia being made after direct inspection of the lesion, if desired. (5) Rewarming is effective while the chest is open, and can be achieved whilst the circulation is maintained with cardiac massage, if necessary. (6) The procedure is simple, clean, and aesthetic, and there is minimal interference with the normal aseptic ritual in the operating theatre.

Our thanks are due to Dunlop Rubber, Australia, Ltd., for donating the special blankets used in this procedure, and in particular to Messrs. Waring and Sharpe of that firm for the time and trouble involved in developing a satisfactory set of blankets for our requirements.

We pay tribute to Mr. V. R. Ebsary, whose ingenuity and initiative were responsible for the development of the hypothermia equipment. This ingeniously contrived

machine has done all that has been required of it in every case in which it has been used. In addition, Mr. Ebsary has attended, in every case in which hypothermia has been employed, to operate the machine for us. Although the machine is simple to use, his skilful regulation of the body temperature has relieved the anaesthetic and surgical staff from any worries in this regard, and has allowed us to concentrate wholly on the medical aspects of the particular case.

Finally, we recognize the contribution of Mr. A. Harper, of the Commonwealth Scientific and Industrial Research Organization, who also gave willingly of his time and knowledge to advise us on certain technical aspects of heat transference, and who kindly attended the theatre for the first few cases to assist in the organization and supervision of this procedure.

REFERENCES

- Bailey, C. P., Cookson, B. A., Downing, D. F., and Neptune, W. B. (1954). *J. thorac. Surg.*, **27**, 73.
 Bigelow, W. G., Lindsay, W. K., and Greenwood, W. F. (1950). *Ann. Surg.*, **132**, 849.
 Brock, R. (1956). *Proc. roy. Soc. Med.*, **49**, 347.
 Cooper, K. E., and Kenyon, J. R. (1957). *Brit. J. Surg.*, **44**, 616.
 Delorme, E. J. (1952). *Lancet*, **2**, 914.
 — (1956). *Proc. roy. Soc. Med.*, **49**, 368.
 Dundee, J. W., Gray, T. C., Mesham, P. R., and Scott, W. E. B. (1953). *Brit. med. J.*, **2**, 1237.
 Khalil, H. H. (1957). *Lancet*, **1**, 185.
 Lewis, F. J., and Taufic, M. (1953). *Surgery*, **33**, 52.
 Lucas, B. G. B. (1955). *Med. Press*, **233**, No. 6055.
 — (1956). *Proc. roy. Soc. Med.*, **49**, 345.
 — (1958). *Brit. med. Bull.*, **14**, 46.
 Ripstein, C. B., Friedgood, C. E., and Solomon, N. (1954). *Surgery*, **35**, 98.
 Ross, D. N. (1954). *Lancet*, **1**, 1108.
 — (1956). *Proc. roy. Soc. Med.*, **49**, 365.
 Swan, H., Zeavin, I., Holmes, J. H., and Montgomery, V. (1953). *Ann. Surg.*, **138**, 360.

TEMPERATURE GRADIENTS DURING HYPOTHERMIA

BY

VICTOR HERCUS,* M.B., M.R.C.P.Ed., D.A.

*Unit of Clinical Investigation, Royal North Shore Hospital,
Sydney, and Congenital Heart Disease Unit, Royal
Alexandra Hospital for Children, Sydney*

DOUGLAS COHEN, M.S., F.R.A.C.S.

*The Institute of Child Health and Congenital Heart Disease
Unit, Royal Alexandra Hospital for Children, Sydney*

AND

A. C. BOWRING, M.B., F.R.C.S., F.R.C.S.Ed.

*Congenital Heart Disease Unit, Royal Alexandra Hospital
for Children, Sydney*

The most commonly used method of reducing the body temperature is by the surface cooling of an anaesthetized subject. A well-controlled method (Cohen and Hercus, 1959) has been used by us in all cases requiring hypothermia for cardiac surgery. Although much experimental work on various aspects of hypothermia has been done, we have been unable to find any record of studies having been made of the changes in temperature of the cerebral cortex in relation to temperature changes occurring simultaneously in other parts of the body. This investigation was undertaken in order to find out what part of the body will reflect most closely the changes in temperature occurring in the cerebral cortex during cooling, stabilization, and rewarming.

*Aided by a grant from the Royal Australasian College of Physicians.

Methods

Temperature measurements were taken with an electrical thermometer,[†] the calibration of which was checked before and during each set of readings. Six separate recordings were taken in the various sites, as listed, at intervals of two minutes. The nasopharyngeal temperature was measured with a mercury thermometer as an additional check on the accuracy of the readings. All leads, together with the mercury thermometers used, were previously calibrated against each other at temperatures of from 25° to 40° C, and were found to record to within 0.1° C. of each other throughout this range.

Cross-bred sheep, closely shorn, weighing 25–35 kg., were anaesthetized with intravenous sodium pentobarbitone and mechanically ventilated.

Leads containing thermistors were then connected to the animal for temperature-recording in the following sites:

1. *Cerebral Cortex*.—A small drill-hole was made in the skull at the postero-medial aspect of the base of the horn. A needle with a thermojunction at its tip was inserted through this hole direct into the cerebral cortex to its full length of 5 cm. It had previously been found, using a bisected sheep's head with the brain *in situ*, that insertion of the special lead (type K8) in this manner would result in the tip of the needle, containing the thermistor, being well within the brain substance.

2. *Central Blood Stream*.—The jugular vein was opened and a lead passed down it to the vicinity of the right atrium.

3. *Oesophageal*.—A standard lead was inserted approximately 30 cm. from the teeth, into the lower third of the oesophagus.

4. *Rectal*.—The large rectal lead was placed 7 cm. within the rectum.

5. *Nasopharyngeal*.—A recording was made of this temperature, using a mercury thermometer, some 6 to 8 cm. from the nostril.

6. *Subcutaneous*.—A lead was left in the subcutaneous tissues of the neck. As expected, the temperatures recorded at this site bore little relation to the other readings and merely served to indicate that peripheral temperature records are without value as an indication of central blood or brain temperature during hypothermia; consequently they are not shown in the Graphs, as they would result in unnecessary complication.

All leads were firmly fixed in position, then the animal was placed in a bath and covered with iced water at 1–2° C. The water was constantly agitated and simultaneous readings were taken from each lead. These were recorded in graph form, together with the bath temperature, at intervals of two minutes (see Graphs). The temperature of the animal, as recorded in the cerebral cortex, was reduced to 29–30° C., and either allowed to drift and stabilize before rewarming or the animal was actively rewarmed in water at 41–42° C. immediately after the cooling was finished.

The results (see Graphs) show how closely the temperature recorded in the lower third of the oesophagus reflected the temperature of the cerebral cortex, this relationship being maintained during cooling, stabilization, and rewarming. As expected, the blood-stream temperature was cooler than the brain during cooling and warmer during rewarming. The rectal and nasopharyngeal temperatures were not so informative as

the oesophageal reading, since they both reflected changes in the blood and brain temperatures very sluggishly.

Discussion

The chief reason for using hypothermia in cardiac surgery is to enable an arrest of the whole or part of the circulation so that the surgeon can perform some task that would be difficult or impossible at normal

Graphs showing the close relationship between temperature of the oesophagus and that of the brain.

[†]The Electric Universal Thermometer, type T.E.3, manufactured by Elektrolaboriet, Copenhagen, utilizing leads types H1, R1, R7, and K8.

temperatures. The safe duration of this circulatory arrest is limited by the viability of the central nervous system—the lower the temperature the longer being the time available (Lucas, 1956). The actual temperature of the brain at the moment that blood flow to it is stopped is the all-important factor in determining the safe period of circulatory arrest. Hitherto it has been assumed that the temperature of the brain substance is reflected closely by that recorded in the nasopharynx (Ross, 1956) or oesophagus (Lucas, 1958), but no actual temperature recording of the cerebral cortex has been shown. Cooper and Kenyon (1957) stated that the rectal and oesophageal temperatures crossed only during rewarming, but we have found in all cases, both clinical and experimental, that the rectal temperature invariably crossed the oesophageal temperature either during cooling or during stabilization, and fell well below it with a large and variable overswing; then, during rewarming, it again always recrossed the oesophageal temperature.

The large drift, or overswing, of the rectal temperature is probably partly due to the rectal contents forming a storage of cold or heat. In addition blood from the skin around the perineum returns to the body via the haemorrhoidal veins, and this blood, during cooling, is much colder than the central blood. This blood must cool the rectal wall and its contents more than the rest of the body and will accentuate the cold-storage effect mentioned above. We have observed that the overswing in temperature and the delay in reflecting temperature changes are often roughly proportional to the quantity of rectal contents.

When the bath is emptied the rectum takes some 15–20 minutes to reach a stable temperature, whereas the central blood, oesophagus, and brain stabilize within five minutes.

Also, when the water in the bath is quickly warmed to 40–42° C. and maintained at this level, after first cooling the animal to 30° C., the brain, central blood stream, and lower oesophageal readings will show a change from cooling to rewarming within five minutes; yet the rectal temperature will continue to fall for ten minutes or more until it sluggishly reflects the changes already obvious in the other leads.

The blood temperature in these experiments is that recorded in the vicinity of the right atrium, and it is probably slightly cooler than the aortic blood during cooling and slightly warmer than it during rewarming. The amount of heat exchange that doubtless occurs after the blood leaves the right heart and passes through the pulmonary circulation prior to entering the left heart and aorta would tend to reduce the gradient between the venous blood temperature, as measured at the right atrium, and the brain temperature.

Cooper and Kenyon (1957) have shown that the oesophageal temperature closely followed the para-aortic temperature during surface cooling by ice-bags, and we have found in clinical cases that the aortic blood temperature is always within 0.2° C. of the temperature in the lower oesophagus (Cohen and Hercus, 1959).

In other words, it is reasonable to assume that the temperature of the brain, the central arterial blood, and the lower oesophagus will always correspond during cooling, stabilization, and rewarming.

The observation that the temperature in the lower third of the oesophagus so closely parallels that of the cerebral cortex during both cooling and rewarming is

most helpful. Whenever hypothermia is employed we can proceed confidently to interrupt the blood supply to the brain, knowing with certainty its temperature at that particular moment.

Hitherto it has been assumed that the temperature of the mid-oesophagus (Delorme, 1956; Lucas, 1958) or the nasopharynx (Brock, 1956) gave a reasonably accurate assessment of the cerebral temperature. The nasopharynx is observed to be unreliable, but it always errs on the "safe" side. Even so, this is undesirable, as unnecessary extra cooling will be undertaken, and this is potentially dangerous.

The mid-oesophagus is more satisfactory, but is still not so accurate as the lower oesophagus in reflecting changes in brain temperature. In clinical cases it is important to ensure that the oesophageal lead is accurately located in the lower third of the oesophagus before proceeding. This is done by carefully measuring the distance that the lead is to be inserted and then moving it both up and down a short distance and checking the reading, as under anaesthesia the readings both in the mid-oesophagus and in the upper part of the stomach will be found to be slightly higher than when the lead has been correctly sited in the lower oesophagus. As cooling is proceeding it may be advisable to move the lead up and down the oesophagus to check the position again; its lower third will be found the coolest place.

Peirce (1958) has shown that cooling induced during extracorporeal circulation results in temperature changes in the brain and oesophagus being almost identical. This confirms our observations during surface cooling.

Summary

Simultaneous temperature records have been taken in the rectum, oesophagus (lower third), nasopharynx, right atrium, and cerebral cortex during hypothermia and rewarming.

The close correlation between the temperature in the lower third of the oesophagus and the cerebral cortex makes it the logical site from which to record the body temperature during hypothermia.

We thank Dr. D. S. Stewart for generously making available facilities at the McMaster Animal Health Laboratory. Mr. F. Hamilton gave us invaluable assistance with the preparation, handling, and anaesthesia of the animals.

REFERENCES

- Brock, R. (1956). *Proc. roy. Soc. Med.*, **49**, 347.
 Cohen, D., and Hercus, V. (1959). *Brit. med. J.*, **1**, 1435.
 Cooper, K. E., and Kenyon, J. R. (1957). *Brit. J. Surg.*, **44**, 616.
 Delorme, E. J. (1956). *Proc. roy. Soc. Med.*, **49**, 368.
 Lucas, B. G. B. (1956). *Ibid.*, **49**, 345.
 — (1958). *Brit. med. Bull.*, **14**, 46.
 Peirce, E. C. (1958). In *Extracorporeal Circulation*, edited by J. G. Allen, p. 221. Thomas, Springfield, Illinois.
 Ross, D. N. (1956). *Proc. roy. Soc. Med.*, **49**, 365.

The Argentine medical journal *El Día Médico* has dedicated a special number to British medicine, sponsored by the British Ambassador in Buenos Aires, Sir JOHN WARD. It is part of the journal's policy to produce such an issue each year on, for example, overseas medicine, congresses, or symposia. The present issue includes articles by Professor CHARLES NEWMAN, Dr. FRANK H. LUMB and Professor MAX ROSENHEIM, Sir CHARLES HARRINGTON, Professor NOEL MACLAGAN, Dr. NORMAN MCKAY, and Dr. NIGEL G. TROTT, Mr. T. HOLMES SELLORS, Dr. A. TALBOT ROGERS, and Dr. F. AVERY JONES. A brief account of the National Health Service is also included.