South African Medical Journal : Suid-Afrikaanse Tydskrif vir Geneeskunde

Cape Town, 5 May 1962 Volume 36 No. 18 Deel 36 Kaapstad, 5 Mei 1962

TEMPERATURE GRADIENTS DURING PROFOUND HYPOTHERMIA WITH EXTRACORPOREAL CIRCULATION

AN EXPERIMENTAL STUDY

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It was Claude Bernard who observed that temperature determinations, made in various vessels within the body cavity at normal body temperature, show a definite variation from site to site.[1] This work was unused until confirmed by Horvath *et al.*,[2] who stated that 'the temperature of the blood throughout the vascular system is not constant . . . Marked thermal gradients were observed, not only in the peripheral blood, but also in the blood draining the organs of the body core'.

It is not surprising that during surface-induced hypothermia these normal temperature gradients become greater. The blood which has passed through the cold surface tissues, must necessarily be colder than that which has passed through the deeper tissues of the body. Cooper[3] pointed out the importance of realizing that these differences are present during hypothermia, since the important temperature to be known is that of the vital organs, not that of the body surface. He also emphasized the fallacy of the widely held belief that recording the oral or rectal temperature would determine the deep body temperature.[3]

Severinghaus and Hercus both confirmed this in their experimental work and concluded that the lower oesophageal temperature is the best guide to core temperature in surface-cooled animals. Hercus *et al.*[4] demonstrated specifically that the lower oesophagus shows the closest correlation to cerebral temperatures. Severinghaus[5,6] was able to show that the temperature varies at different depths in the rectum, and pointed out that 'of course, a thermometer, if surrounded by faecal matter, may respond sluggishly to rectal temperature changes'.

The creation of an internal temperature gradient is the basis of the success of inducing hypothermia *via* an extracorporeal circuit. Cold blood passes into the body, and the organs with the richest blood supply (and hence the greatest metabolic activity) cool quickest. The great advantage of extracorporeal cooling with an oxygenator, therefore, is that the high-oxygen-consuming tissues are cooled the quickest and, on rewarming, are supplied with adequate oxygen.[7] Early workers were aware of the thermal gradients produced during extracorporeal circulation hypothermia,[8] and Gollan *et al.*[9] noted that only the temperatures of the vital organs (the heart and brain) and the oesophagus really fall to low levels. Subsequently, it was learned that the heart, liver and kidneys cool the quickest, with the brain and mid-oesophagus cooling at a slightly slower rate.[10] Kenyon *et al.*[11] also described the temperature gradients, and in the experiments of Shields and Lewis[12] the brain did not cool as rapidly as expected, whereas the lowest temperature was recorded in the liver, and the muscles cooled to only 32°C. The importance of comparing the thermal gradients induced by various techniques led Enerson *et al.*[13] to propose the use of their 'selective cooling index' as a working index of the differential cooling noted with internal hypothermia.

Despite abundant evidence that thermal gradients are produced in blood-stream hypothermia, the fallacy of using temperatures such as rectal or oral as a guide to the vital-organ temperature, is still not generally appreciated. As recently as 1960, a group of workers in the field of profound hypothermia published a report of their experimental observations (including one patient), in which the temperature recorded was the pharyngeal.[14]

Experiments undertaken in our laboratory to develop a technique of inducing profound hypothermia using the bubble oxygenator and an efficient heat exchanger, showed that the low mid-oesophageal temperature correlates closely with that of the vital organs, including the brain.[15] This was later confirmed during experiments using autogenous oxygenation.[16]

On testing an apparently suitable technique before clinical use, a careful note of the low mid-oesophageal temperature was made in all experiments. In addition to the study of many parameters, the temperature gradients occurring in various parts of the body were observed.

These temperature gradients will be discussed, paying particular attention to the last 2 dogs in the series, in which the temperatures were recorded simultaneously at various sites. The purpose of this paper is to emphasize the importance of temperature gradients and the usefulness of using the low mid-oesophageal temperature as a guide to the vital-organ temperature.

MATERIAL AND METHODS

In 19 consecutive experiments (Table I), healthy adult mongrel dogs were subjected to profound hypothermia, using our technique of extracorporeal cooling with the bubble oxygenator. This was essentially similar to that subsequently used, and described, for our patients.[17]

In dogs 18 and 19, temperatures were recorded simultaneously at multiple sites. Two other dogs in the series, 15 and 17, were also selected for discussion, since they were representative of the findings in the remaining dogs.

TABLE I. AN OUTLINE OF THE 19 CONSECUTIVE EXPERIMENTS IN THIS SERIES

Dog no.	*Weight in kg.*	*Duration of bypass (in minutes)*	*Lowest oesophageal temperature in °C.*
1	15	70	6·9
2	15	90	11·0
3	21	106	9·3
4	17	89	11·0
5	20	71	10·2
6	17	86	11·4
7	14	60	10·0
8	18	229	14·8
9	18	75	11·0
10	15	60	9·2
11	18	66	10·9
12	18	62	9·8
13	15	77	11·0
14	17	90	9·2
15	20	65	10·0
16	23	61	13·8
17	14	73	10·0
18	21	62	8·7
19	17	68	10·5

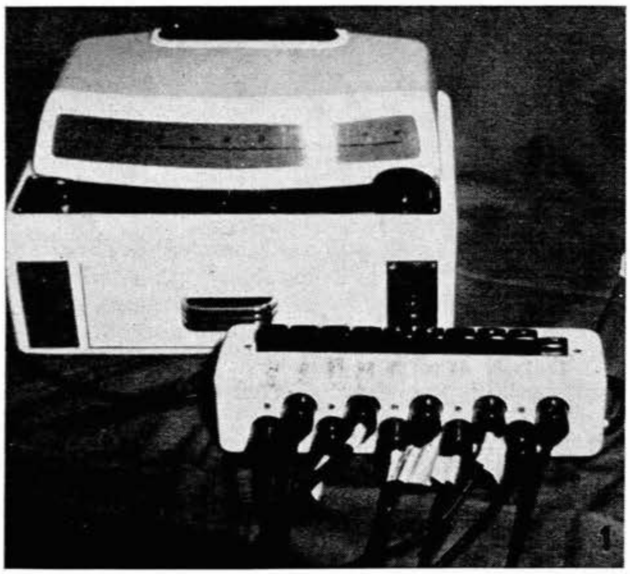

Fig. 1. The Electric Universal Thermometer. Various leads can be seen in the foreground, attached to the junction box.

The temperatures were recorded using the Electric Universal Thermometer, type TE-3, with leads types R-7, OSG-1, K-8 and K-3, and a connection box, type FE-10 (Fig. 1).* During the course of the experiments, the various temperatures were recorded at 1- or 2-minute intervals.

Before starting each experiment, the oesophageal temperature electrode (type OSG-1) was inserted to lie in the lower mid-oesophagus, and the rectal temperature lead (type R-7) was inserted approximately 2½ inches into the rectum. Once the dog's chest was open, the position of the oesophageal lead was checked, and altered if necessary. After assembly of the bypass apparatus, 2 needle temperature electrodes (types K-3 or K-8) were inserted into the Mayon tubing of the arterial line, so that they were situated in the blood stream, one on each side of the heat-exchange unit. The temperature of the blood entering and leaving the heat exchanger could thus be recorded.

In dogs 18 and 19, in addition to the above, the inferior vena caval blood temperature was recorded, using lead OSG-1 inserted into the inferior vena cava *via* the right femoral vein. The brain temperature was recorded using a needle electrode type K-8, inserted to the hilt into the substance of the left cerebral hemisphere through a burr hole.

In addition, in dog 18 the posterior pericardial temperature was recorded using a lead OSG-1, inserted behind the heart in the posterior pericardium. The neck and left-thigh muscle temperatures were also recorded in this dog, using needle electrode leads K-8.

* Manufactured by Elektrolaboratoriet, Copenhagen, Denmark.

RESULTS AND DISCUSSION

Figs. 2 - 5 represent in graphic form the temperatures recorded at various sites in the dogs to be discussed. Figs. 2 and 3 demonstrate the 2 different patterns of change in the rectal temperature, while Figs. 4 and 5 demonstrate the variations in temperature at numerous sites.

DOG 15.

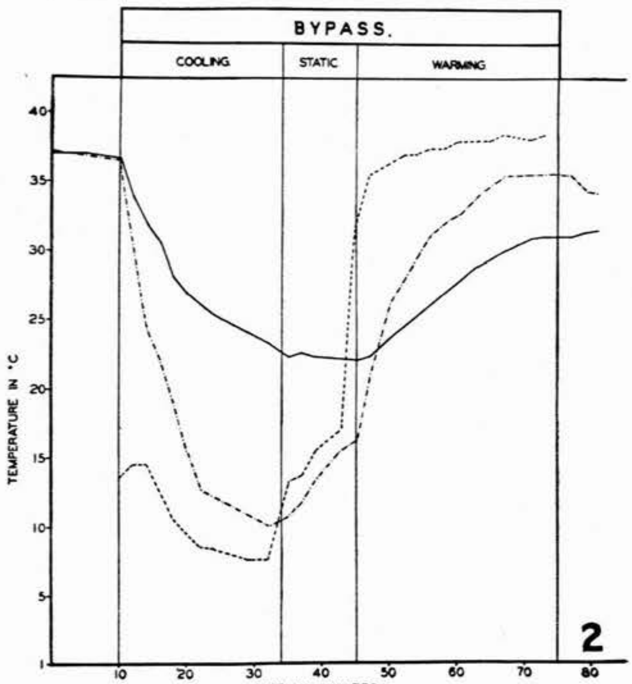

Fig. 2. Temperature gradients that occurred during the hypothermic perfusion of dog 15. 'Rectal', 'oesophageal' and 'in dog' temperatures are represented by lines similar to those in Fig. 3.

1. *Low Mid-oesophageal Temperature*

In these graphs, the close relationship between the low mid-oesophageal temperature, the vital organs and the blood draining from the body, is clearly depicted. For example, in dog 18 (Fig. 4), the temperatures in the oesophagus, the heart (posterior pericardial), the draining blood, and the blood in the inferior vena cava, were closely related throughout bypass.

The relationship of oesophageal to brain temperature will be discussed later. These observations are felt to confirm the previous opinion that the 'low mid-oesophageal temperature' is the 'most easily recordable, and the most accurate guide to the temperatures of the vital organs'.[16]

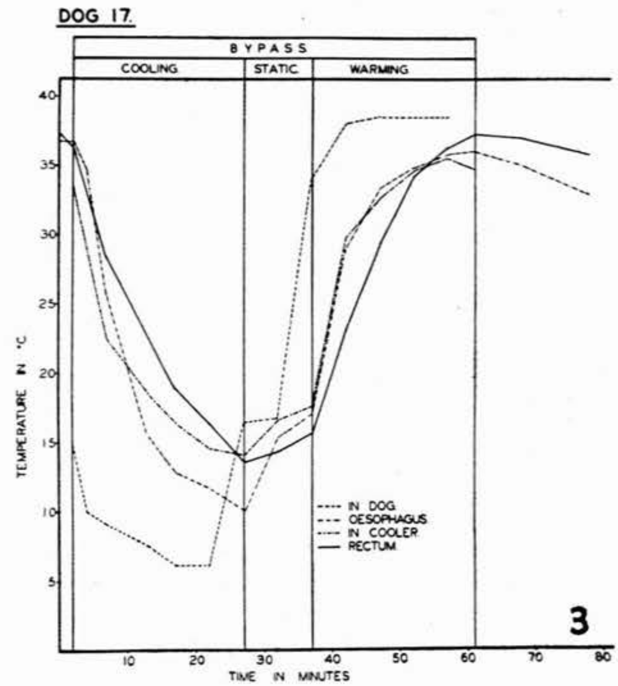

Fig. 3. Temperature gradients that occurred during the hypothermic perfusion of dog 17.

2. *Rectal Temperature*

Two patterns of variation in rectal temperature occurred during bypass. The first was demonstrated by dog 15 (Fig. 2), in which the rectal temperature lagged relatively far behind the oesophageal temperature (and hence behind the vital-organ temperature), and only dropped to 22°C. During rewarming, the rise was slow and the final temperature attained at the end of perfusion was under 32°C. This pattern occurred in 9 of the 19 dogs.

In the remainder, the fall and rise of rectal temperature followed that of the low mid-oesophagus much more closely, as demonstrated by dogs 17 - 19 (Figs. 3 - 5). However, it did lag behind the oesophageal temperature to some extent. A similar picture was found in some of our earlier experimental work.

The reason for this variability in rectal temperature is not at all clear, but its presence emphasizes the inaccuracy of the rectal temperature as a guide to vital-organ temperature. It is possible that the rectal lead was not inserted to exactly the same depth in all dogs, and that in some it was even imbedded in faeces.[5]

3. *Brain Temperature*

The temperature recorded in the brain in dog 19 (Fig. 5) followed fairly closely that of the low mid-oesophagus, as it did in our earlier findings.[16] This tends to confirm the previous opinion that the brain temperature, like that of other vital organs, is accurately indicated by the low mid-oesophageal temperature.

In dog 18 (Fig. 4), however, the fall and rise was a little slower than anticipated. It is of interest that the brain temperature in this dog corresponded more closely to the rectal temperature than to the oesophageal. (This was one of the dogs in which a marked fall in rectal temperature occurred.)

Although the reason for this is again not clear, it is important to realize that it might occur. Thus, total cessation of circulation at a fairly high oesophageal temperature for any length of time might be hazardous, should a delayed fall in brain temperature occur. This is a good indication for maintaining at least a low flow of oxygenated blood throughout the course of cardio-pulmonary bypass with hypothermia, and supports the technique used in this series in preference to that described by Drew *et al.*[18,19] and by ourselves in the past.[16]

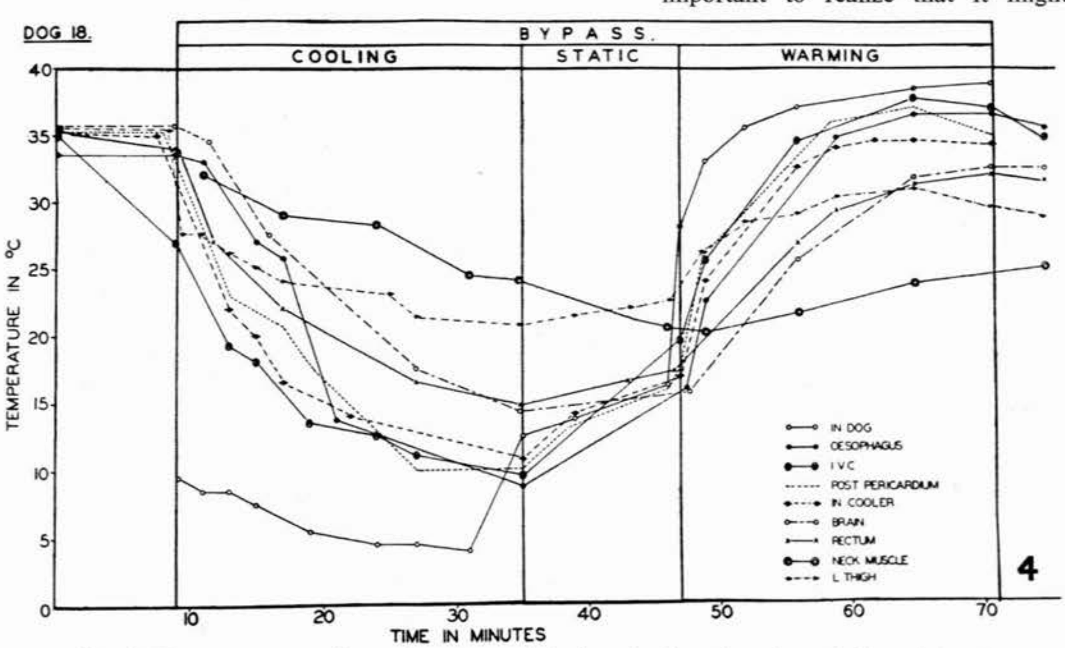

Fig. 4. Temperature gradients that occurred during the hypothermic perfusion of dog 18.

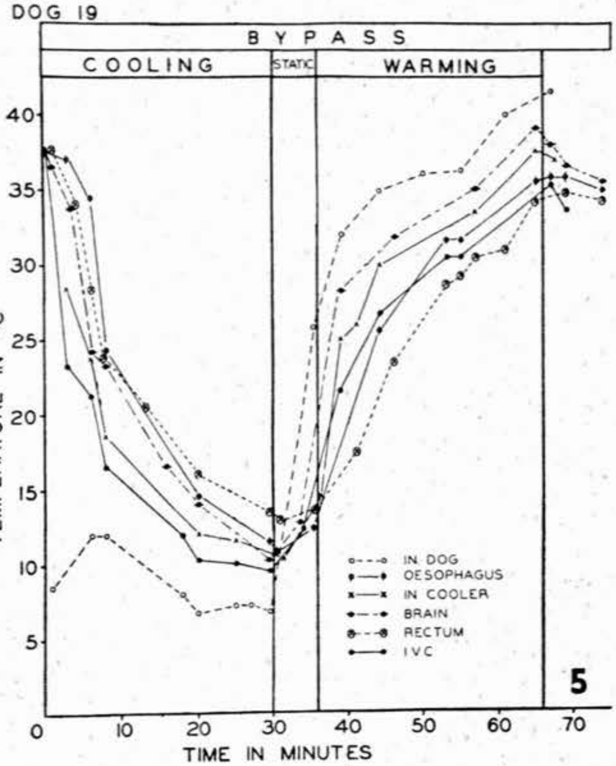

Fig. 5. Temperature gradients that occurred during the hypothermic perfusion of dog 19.

4. *Posterior Pericardial Temperature*

The variations that occurred in the posterior pericardial (and therefore in the heart) temperature, are shown in Fig. 4. There was a very close correlation indeed to the low mid-oesophageal temperature. This again shows the value of the low mid-oesophageal temperature as a guide to vital-organ temperatures.

5. *Inferior Vena Caval Blood Temperature*

In dogs 18 and 19 this temperature correlated closely with that of the blood leaving the dog, which indicated that the temperature of the blood of the lower half of the body was similar to that of the entire body. In both cases the rectal temperature fell fairly low. It is possible that, in the dogs in which the rectal temperature did not fall so low, the inferior vena caval blood from the lower half of the body was not as cool as that leaving the upper half of the body.

6. *Neck and Left-thigh Muscle Temperatures*

A slow fall and rise occurred in these temperatures in dog 18 (Fig. 4). This clearly demonstrates the point that, during this type of hypothermia, the temperature of the non-vital organs lags well behind that of the vital organs.

A considerable 'after drop' occurred in the neck muscle temperature after cessation of active cooling. A similar 'after drop' occurs in surface hypothermia, but here it is the vital organs that continue to cool.[20]

SUMMARY AND CONCLUSIONS

In this paper, the temperature gradients that occurred in 4 representative dogs of a series of 19 subjected to profound hypothermia are discussed. In concluding, the important factors which have been brought to light are enumerated:

1. The low mid-oesophageal temperature is a useful and relatively accurate guide to the vital-organ temperature.

2. A wide variation occurs in rectal temperature during this type of hypothermia. At times, it corresponds fairly closely to the oesophageal temperature, but at others it lags behind considerably. Possible explanations are mentioned. This variation makes the rectal temperature an inaccurate guide to that of the vital organs.

3. The brain temperature is closely indicated by the low mid-oesophageal temperature. However, it may lag a little behind and, therefore, the total cessation of circulation for any length of time at a fairly high oesophageal temperature may be hazardous. The perfusion of the body with oxygenated blood (even at low flow rates) during the hypothermic phase is thus safer. This is another indication for employing the perfusion technique used in this series in preference to the autogenous oxygenation technique.

4. During this method of hypothermia, the temperature of the non-vital organs lags well behind that of the vital organs. An 'after drop' in temperature in the non-vital tissues may occur after active cooling has ceased, in contradistinction to surface cooling in which the 'after drop' occurs in the vital organs.

We wish to express our thanks to Prof. J. H. Louw of the Department of Surgery of the University of Cape Town for his encouragement. The work would have been impossible, furthermore, without the assistance of the technical staff of the J. S. Marais Laboratory: Messrs. C. C. Goosen and D. Evans, and Mrs. V. M. Connell. We thank Mrs. E. P. Kottler for the diagrams and Mr. G. McManus for some of the photography. Finally, our acknowledgements are due to the Dr. C. L. Herman Research Fund of the University of Cape Town, which financed this work.

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