A STUDY OF BODY TEMPERATURE DURING GENERAL ANAESTHESIA*

BERNARD WALTMAN** and JOHN W. SCOTT, M.A., M.D.***

ALTHOUGH the vernacular phrase "out cold" was in use to describe the state of anaesthesia well before 1885, not until that year was clinical evidence presented to verify this homely observation, when Kappeler (1) noted that during narcosis produced by ether or chloroform a patient's body temperature might fall as much as 1.5° C. in one hour. Hare (2) found that even greater losses occurred in the axillary temperature during etherization and in dogs he observed decreases of 8-10° F. rectal temperature during an hour. Allen (3) confirmed the tendency of the etherized dog to become hypothermic at room temperatures of 65-75° F. (18-24° C.) but he also demonstrated that the fluctuation in temperature could be reversed by the application of external heat or at a room temperature of 93-96° F. (34-36° C.). Similar results with dogs were obtained by Mills (4). Davis (5) in a series of animal experiments showed that the use of wet towels aggravated the heat loss, but that if the ether vapour was warmed the rectal temperature would remain stationary, even at a room temperature of 21° C. He observed during 165 surgical anaesthetizations by the open drop ether technique that the rectal temperature fell less if the patient was covered and dry, than if he was exposed and moist. In addition, he found that as the operating room grew warmer, the average loss decreased from 0.75° C. at 24.0° C. to only 0.07° C. at 32.5° C. room temperature.

That the etherized dog actually becomes poikilothermic was conclusively demonstrated by Barbour and Bourne (6) in 1923; they showed that normal dogs under ether anaesthesia are so lacking in ability to regulate their body temperature that it remains constant only at an environmental temperature of 30.5° C. in either wet or dry atmospheres. In the child as well, homeothermic regulation is profoundly disturbed during anaesthesia; at operating room temperatures of only 76-82° F. (24-28° C.) Bigler and McQuiston (7) found that 62 per cent of anaesthetized children became hyperthermic and even cooling with ice bags or a water mattress from the start of the operation could not prevent increases in rectal temperature above 100° F. (38° C.) in 40 per cent of the cases. In adult man, the evidence for poikilothermia during anaesthesia has not been so conclusively demonstrated. Watkins and Wilson (8) found that although heat losses occurred at ambient temperatures below 70° F. (21° C.), even in long operations only relatively small decreases in rectal temperature were noted. Léger (9) observed maximum hypothermias of 1.5° C. and 0.8° C. for inhalation and spinal anaesthesia respectively. Post-operative heat stroke has been attributed to high operating room temperatures (10, 11) and at air temperatures

*From the Department of Anaesthesia, University of Toronto, and the Anaesthetic Service, Toronto General Hospital.

**Department of Anaesthesia, Toronto General Hospital and University of Toronto

***Clinical Teacher in Medicine, University of Toronto, and Department of Electroencephalography, Toronto General Hospital.

above 85° F. (29° C.) the use of the closed soda-lime absorber technique has produced hyperthermias of 5–7° F. Although Searles and Lenahan (12) consider the anaesthetized patient to be poikilothermic and the room temperature the most important factor modifying rectal temperature, Smith (13) while investigating the aetiology of ether convulsions, measured the theatre air temperature, air velocity, relative humidity and temperature under the drapes of 62 operating cases and 22 controls and concluded that there was “absolutely no correlation between the theatre temperature and rectal temperature.”

More recently Clark, Orkin and Rovenstine (14) inferred from a study of 164 adult patients that the wet bulb temperature is the most satisfactory measure of the thermal tolerability of the operating room environment. They found that between 58 and 75° F. (14 and 24° C.) wet bulb, rectal temperatures rose but not excessively and heat retention occurred only once in 119 individuals. Above 75° F. (24° C.) wet bulb, rectal temperatures increased 1.2–2° F. per hour and heat retention occurred in 9 cases out of 45. In both wet bulb ranges the closed to-and-fro rebreathing system was associated with greater temperature increases than either the closed circle rebreathing system or the non-rebreathing system.

The temperature of the skin during anaesthesia has also been studied. Foged (15) observed that both ether narcosis and spinal anaesthesia normally caused an average increase of 5° C in the skin temperature of the foot. Others (16, 17, 18) have shown that the increase is as great as that following sympathectomy and that in the dog vasoconstriction in response to a sudden decrease in environmental temperature does not occur. Foregger (19) has demonstrated maximum increases in the cutaneous temperature of the great toe by inhalation of nitrous oxide, ethylene, cyclopropane, ether and chloroform, by intravenous pentothal, and by spinal procaine. The phenomenon occurred in the first stage of anaesthesia and was not associated with a fall in arterial blood pressure.

In some preliminary measurements in an air-conditioned operating suite, Scott (20) observed depressions of 4 and 5° C. in the rectal temperature of several neurosurgical patients. It was decided to investigate these findings more thoroughly in the present study and because the work was done during the summer months, to extend the observations to operating rooms which were not mechanically cooled, in an attempt to determine more accurately the factors regulating body temperature during anaesthesia.

MATERIALS AND METHODS

The behaviour of the rectal, skin, and muscle temperature and of the sweat glands in 35 afebrile adults ranging in age from 17 to 72 years, undergoing general anaesthesia of at least one hour's duration, was studied. In each instance a description of the thermal environment in terms of dry and wet bulb temperatures and air velocity was obtained. None of the patients suffered shock and all survived the operative procedures.

Temperatures were measured with an “Ellab” thermometer type T.E. 3 (manufactured by Electrolaboriet, Copenhagen) which is a mirror galvanometer compensated for use at room temperatures of 10–31° C. and reading directly in degrees Centigrade from a variety of thermocouple applicators. Readings were

taken at six-minute intervals. An applicator consisting of a thermojunction within a bright metal plug was inserted 8–12 cm. into the rectum when anaesthesia was achieved. A bare wire thermocouple set in a plastic holder was attached to the surface of the lower limb with adhesive tape in such a way that the junction was left uncovered; a loop of wire containing a thermojunction was similarly applied to the great toe. A few readings of skin temperature were usually made before anaesthesia was induced. Muscle temperature was measured with a thermocouple set in the point of an injection-type needle which had a removable outer cover which could be sterilized. A thermocouple was suspended at the foot of the operating table to measure room air temperature (dry bulb) while a bare wire thermocouple set in a plastic rod was fixed beneath the surgical drapes 6–8 cm. from the lateral surface of the patient's thigh. The accuracy of the instrument was ascertained at $\pm 0.1^\circ \text{C}$. and all applicators used read within $\pm 0.1^\circ \text{C}$. of each other. Although the accuracy of the surface temperature readings was not separately determined, others (21) have reported an accuracy of $\pm 0.15^\circ \text{C}$. with similar devices.

The wet bulb temperature was measured at thirty-minute intervals with a sling psychrometer accurate to 0.5°F . or in some cases in the air-conditioned theatre the relative humidity was read from a wall hygrometer and the corresponding wet bulb value obtained from psychrometric tables. Air velocity was determined at a distance of 6 feet from the patient with a silvered kata thermometer (cooling range $130\text{--}125^\circ \text{F}$.).

The presence or absence of sweating was demonstrated by Minor's method (22): the skin of the dorsum of the foot, the calf or the face was painted with a solution of iodine (iodine 2 gm., castor oil 10 ml., absolute alcohol to 100 ml.) and dusted with dry rice starch.

The neurosurgical patients were anaesthetized in an anteroom and then transferred to the air-conditioned operating room. The others were anaesthetized in operating rooms which were ventilated by open windows or in one instance by fans. In addition, the neurosurgical draping procedure differed in that the drapes, by being carried over an instrument stand elevated above the centre of the operating table, were held away from the body and permitted access to the patient by the anaesthetist; in other surgical procedures the drapes fell directly upon the patient. Preoperative medication consisted of atropine 0.6 mg. or 0.4 mg. in all but one case, with morphine 10 mg. in 16 cases and Demerol 50–100 mg. in 9 cases.

Anaesthesia was induced in all patients with intravenous Pentothal Sodium in total dosages of 0.2–1.0 gm. Muscular relaxation was achieved in all cases by the intravenous administration of one or two of the following:

- Succinylcholine chloride 20–80 mg. 19 cases;
- D-tubocurarine chloride 9–22 mg. 3 cases;
- Flaxedil 4–5 mg. 3 cases;
- Decamethonium bromide 2–5 mg. 7 cases.

Anaesthesia was maintained by inhalation using a variety of anaesthetic agents. Three systems were used for administration: the closed circle rebreathing

system, the semi-closed partial rebreathing, and the non-rebreathing system. Gases were introduced by endotracheal intubation, by endopharyngeal airway with cup, or via a tracheotomy. Table I shows the various combinations of agents and techniques employed and their distribution among the cases studied. Some of the totals exceed 35, the total number of patients, because occasionally more than one technique was used during a single operation.

TABLE I
ANAESTHETIC AGENTS, BREATHING SYSTEMS, AND AIRWAYS USED

<i>Breathing System</i>	Non-rebreathing	Semi-closed	Closed	Totals
<i>Number of cases</i>	2	22	14	38
ANAESTHETIC AGENTS				
Cyclopropane	0	0	3	3
Ether	0	1	8	9
Ether-cyclopropane	0	0	1	1
Nitrous oxide (N ₂ O)	1	5	0	6
N ₂ O-Trilene	1	5	1	7
N ₂ O-ether-Trilene	0	4	0	4
N ₂ O-cyclopropane	0	1	0	1
N ₂ O-ether	0	6	1	7
AIRWAY				
Endotracheal Tube	1	17	11	29
Endopharyngeal Airway with Cup	1	4	2	7
Tracheotomy	0	1	0	1

Intravenous fluids were continuously administered to 31 patients during their anaesthesia. Of these, all received saline, 20 also received blood, and 3 dextran. The mean volume received was 1,000 cc. In 12 cases the blood was administered at refrigerator temperature (about 5° C.).

RESULTS

The extent and direction of the changes observed in the rectal temperatures are shown in Figs. 1, 2, and 3. For each of the three groups of environmental conditions the deviations from the value at the time of induction (0 hours) have been plotted at successive intervals of 18 minutes. A smooth curve joins the average change at each interval. The distribution into the three groups was made according to the mean ambient dry bulb temperature, calculated for each case. The wet bulb temperatures simultaneously observed have been indicated also.

The mean rectal temperature at induction was $37.2 \pm 0.4^{\circ}$ C. (S.E. of mean of 35 observations) and the range 36.2–38.0° C. Thereafter, with one exception mentioned below, no rectal temperature was observed beyond the limits 36.0–38.6° C. and in only 4 cases was 38.0° C. exceeded. The mean duration of

FIG. 1 Rectal temperature changes during anaesthesia at air temperature of 20.1-23.0° C. Time of induction is 0 hours

FIG. 2. Rectal temperature changes during anaesthesia at air temperature of 23.1-26.0° C. Induction at 0 hours.

FIG 3 Rectal temperature changes during anaesthesia at air temperature of 26.1-29.0° C. Induction at 0 hours.

anaesthesia was 2 hours 51 minutes $\pm$ 1 hour (35 obs.) with a range, 1 hour-5 hours 30 minutes.

One rectal temperature record was not included in the accompanying charts. In this case the mean dry bulb temperature of the room (19.0° C.) was the only value observed below 20.1° C. and although a marked change in rectal temperature occurred, no separate graph was drawn. This patient was anaesthetized through a tracheotomy tube with the semi-closed partial rebreathing system; his rectal temperature fell from an initial 37.3° C. to 34.1° C. during 4 hours of anaesthesia, although in the final hour the decline was less marked than earlier. No shivering was observed.

In 16 other cases in which the rectal temperature showed decreases of 0.3-1.2° C. shivering was noted in only one case. This patient had received 3 mg. decamethonium bromide as a muscular relaxant. The mean air temperature was 22.2° C. The shivering continued without interruption for 2 hours; the mean rectal temperature was constant at $37.1 \pm 0.1^\circ$ C., after having fallen 0.8° C before shivering commenced.

The temperature of the quadratus femoris muscle was observed in 4 cases. The mean muscle temperatures were

$0.9 \pm 0.1^\circ$ C, $1.0 \pm 0.1^\circ$ C, $1.4 \pm 0.2^\circ$ C, and $2.2 \pm 0.4^\circ$ C

below the respective rectal temperatures. In two cases the curves of rectal and muscle temperature were parallel, but in the other two cases they diverged with the progress of the operation.

The behaviour of the temperature of the plantar surface of the great toe and of the lateral surface of the thigh is described in Figs. 4 and 5 respectively. Absolute skin temperature readings are plotted at successive intervals of 18 minutes from the time of induction of anaesthesia and the mean values joined by a curve. Records of the skin temperature of the plantar surface of the heel in 5 patients, and of the medial surface of the calf in 6 patients were also obtained. The temperature of the heel behaved much like that of the toe, while the changes observed in the calf were similar to those in the thigh. Except at 0 hours when the patient was not yet unconscious, the level of the skin temperature and the air temperature were apparently independent. A comparison between the skin temperature changes and the rectal temperature changes was made in each case, but no relation was apparent.

A satisfactory description of the activity of the sweat glands in the selected skin areas was obtained for 14 patients. In cases where Minor's test showed sweating on exposed parts, unevaporated sweat was found on other parts of the body when the drapes were removed at the end of the operation. The results are shown in Table II and additional information about ambient dry bulb temperature, rectal temperature, and the administration of intravenous fluids is also given.

Air movement in the air-conditioned operating room was 49 ± 10 feet per

FIG 4 Skin temperature of plantar surface of the great toe during anaesthesia

FIG. 5. Skin temperature of lateral surface of the thigh during anaesthesia.

TABLE II

SWEATING DURING ANAESTHESIA

	Case	Mean dry bulb temp., °C.	Intravenous fluid, c.c.	Max. variation in rectal temp., °C.
Sweating observed	La.	29.0	900	± 0.2
	Ma.	28.8	800	$+0.4$
	Cr.	28.6	500	$+0.3$
	Kr.	28.0	1100	$+0.4$
	Lo.	27.0	0	$+0.2$
	Ba.	27.1	2500	$-0.4 + 0.5$
	v.B.	26.8	1200	-0.6
	Hi.	24.9	600	-1.2
	Mean	27.5 ± 1.3	950 ± 660	-0.05 ± 0.5
No sweating observed	Co.	27.3	0	$+0.6$
	Sm.	27.3	900	$+0.7$
	Ol.	26.2	250	-0.3
	Ro.	26.0	500	$+1.0$
	Fr.	25.6	500	$+0.5 - 0.3$
	Ca.	25.8	0	$+0.5$
	Mean	26.4 ± 0.7	360 ± 310	$+0.4 \pm 0.4$

minute (5 obs.); in the operating rooms ventilated by open windows, 17 ± 25 f/m (20 obs.), in one room containing 2 fans, 164 ± 15 f/m (4 obs.). In no case could variation in rectal temperature be attributed to the effect of air movement as measured, i.e., at a distance of 6 feet from the patient.

In 12 patients receiving cold blood into a leg vein, rectal temperatures were observed to rise, fall, or remain constant during the time of infusion.

The temperature of the air adjacent to the body under the drapes exceeded the temperature of the air in the cooled neurosurgical theatre by $3.6 \pm 1.8^\circ \text{C}$. (5 obs.), and in the other operating rooms by $3.9 \pm 1.0^\circ \text{C}$. (14 obs.).

DISCUSSION

At any level of activity in the conscious patient or during anaesthesia, the temperature of the interior of the body can be maintained at a constant value only when heat loss to the environment equals heat production or gain. If such a balance does not exist the temperature will change.

Although quantitative information is not available, the existing evidence suggests that heat production in anaesthetized man is less than the basal metabolic rate. Admittedly the quantity of heat produced by skeletal muscle in the basal state is not large (23, 24) but when anaesthesia supplemented by curarization supervenes, muscular relaxation is more complete and the contribution of skeletal muscle to the total heat production is further reduced. The specific dynamic action of foods does not augment heat production because patients entering the operating room have been fasting for at least 10 hours. In addition, further depression of the metabolic rate may be caused by morphine (25, 26) and by certain barbituric acid hypnotics (27). Atropine in doses of gr. 1/50 has been shown to elevate the metabolic rate (28, 29) but smaller doses were used in this study.

When the air temperature falls sufficiently, usually below 19°C . (30, 31), conscious resting man supplements heat production first by increased muscular tension and then by shivering. If muscular relaxation is complete these mechanisms are not available to the anaesthetized patient.

During surgical procedures heat may be gained from the environment from the operating room lamps, from hot laparotomy pads and from the anaesthetic machine when the soda-lime absorber is in use.

Heat loss to the environment occurs by transfer from the skin and lungs, by radiation to distant cooler objects, conduction to the air, and evaporation of water.

Heat exchange by radiation from the skin is a function of the effective radiating surface of the body and the difference between skin temperature and the surface temperature of distant objects "seen" by the effective surface. During surgical anaesthesia radiative loss is therefore assisted by the high skin temperature produced by maximal cutaneous vasodilatation, but hindered by the presence of the hotter operating lamps and by the intervention of the surgeons' bodies between the patient and cooler objects. Transfer by radiation becomes impossible if the temperature of the environment rises above the upper limit of skin temperature.

Thermal conduction to the adjacent air depends upon the area of skin in con-

tact with the air and the surface-to-air thermal gradient. Air movement by natural or forced convection maintains the thermal gradient by replacing the warmed air at the skin surface with cooler air. However, surgical draping creates a "private climate" about the patient's body which is so unsusceptible to erosion by the room air that when air velocities of 50 feet per minute are recorded, the air temperature at a distance of 6-8 cm. from the skin is almost 4° C. above the temperature of the moving air. The result is that while a reclining nude subject can lose heat to the air at temperatures reaching 34° C. (20), conductive heat loss in the operating room becomes seriously impaired as the air temperature approaches 30° C.

Evaporation of insensible perspiration from the skin dissipates about 15 per cent of the total heat loss at air temperatures between 18-30° C., the remainder being lost by radiation and conduction (32). If transfer by these means becomes inadequate, the sweat glands become active. For nude reclining man this occurs at an air temperature of 31° C., when he is lightly clothed at 29° C. (32). For recumbent anaesthetized man under drapes the temperature at which sweating commences is lower, the mean value obtained in this study being 27.5° C.

Sweating is effective as a cooling mechanism because water when evaporated absorbs heat. The rate of evaporation varies inversely with the relative humidity: consequently as the wet bulb temperature approaches the dry bulb, the effectiveness of sweating as a cooling mechanism is reduced. The body can increase the cooling effect by increasing the area of skin that is wet with sweat, and air movement increases the rate of cooling by speeding evaporation. Atropine and scopolamine reduce sweating by as much as 35 per cent (33) and hence limit the capacity of the sweat glands to cool the body.

In each of 10 cases of heat retention during anaesthesia observed by Clark *et al.* (14) cessation of sweating occurred. Searles and Lenahan (12) reversed a hyperthermic trend in an anaesthetized patient by intravenous fluid therapy and Bourne (34) has shown that in dogs etherization at 33° C. produces negligible changes in body temperature when fluids are administered. In this study, although the difference between the mean volume of fluid received by patients who did not sweat was significantly less than the mean volume of fluid received by sweating patients, there was also a significant difference between the mean ambient air temperature for sweating and non-sweating patients, and so perhaps the evidence is inconclusive for establishing a relation between sweating ability and intravenous therapy during surgical anaesthesia. Unfortunately Clark *et al.* (14) have not indicated whether their patients received intravenous fluid.

The lungs dissipate heat chiefly by warming inspired air to 32-35° C. and saturating it with water to 95 per cent (35). For a man with a basal metabolic rate of 71 kg. cal./hour, Clark *et al.* (14) have calculated that by breathing into an anaesthetic machine he loses 16 per cent of his total heat production when the non-rebreathing system is used, 4 per cent when the closed circle system is used, and that he gains 4 per cent when the closed to-and-fro system is employed. A loss of 10 per cent can probably be assumed for the semi-closed partial rebreathing system. Normally vaporization from the skin can increase to compensate for diminished loss from the lungs (36), but when the sweating mechan-

ism is impaired these figures become important. Thus in cases where sweating had ceased and heat retention occurred, the to-and-fro system was most commonly in use (14).

The administration of blood at refrigerator temperature has little effect upon rectal temperature (37).

The exposure of deep tissues through a large skin incision may be an important avenue of heat escape, especially when the air is cool.

In addition, the thermoregulatory centres of the central nervous system may be depressed by the anaesthetic and so become less efficient in their action; certainly the control is seriously disturbed in the anaesthetized child (7).

From these considerations it is not unreasonable to expect that in cool environments the cutaneous vasodilatation and the muscular relaxation achieved during anaesthesia may embarrass the normal response to cold, while in hot environments the described hindrances to radiative, convective, and evaporative heat loss should predispose to hyperthermia, and certainly these situations have developed (20, 38). However, in this study, at air temperatures of 20.1-29.0° C. dry bulb, and 14.8-25.6° C. wet bulb, under the described condition of surgical anaesthesia, only slight variations in rectal temperatures were observed and certainly no serious impairment of thermoregulation occurred.

At an air temperature below 20° C. one case in this study showed a marked hypothermia, but further investigation is necessary to clarify the circumstances under which such changes occur.

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SUMMARY

1. Physiological reactions of 35 afebrile adults to the thermal environment during surgical anaesthesia were studied.

2. In the air temperature range 20.1-29.0° C. dry bulb and 14.8-25.6° C. wet bulb observations on the rectal temperature indicated no embarrassment of thermoregulation.

3. The mean air temperature at which sweating occurred was 27.5° C.

4. Skin temperatures along the lower limb rose quickly after induction of anaesthesia to within a few degrees of rectal temperature and generally remained high throughout anaesthesia.

5. Possible factors influencing heat regulation during surgical anaesthesia are discussed.

RÉSUMÉ

Des enquêtes antérieures sur la température des malades anesthésiés ont suggéré que des troubles de la régulation thermique peuvent se produire et que les fluctuations observées dans la température rectale, peuvent être influencées par l'état thermique de la salle d'opération.

Dans la présente étude, on a observé les températures rectales, musculaires et

cutanées et l'activité des glandes sudoripares chez 35 adultes soumis à une anesthésie générale. En même temps on a noté les descriptions des températures prépondérantes (ampoule sèche et ampoule humide) et des mouvements de l'air.

On a constaté que, pour des températures s'étendant de 20, 1° à 29° C. (ampoule sèche) et de 14, 8° à 25, 0° C. (ampoule humide), les températures rectales subissaient peu de variations pendant une intervention durant en moyenne trois heures et que la régulation thermique n'était pas affectée. Les températures cutanées le long du membre inférieur montaient rapidement après le début de l'anesthésie jusqu'à atteindre, à quelques degrés près, la température rectale et en général se maintenaient élevées jusqu'au bout. La température moyenne de l'air lorsque la sudation apparaissait était de 27, 5° C., ce qui est quelque peu plus bas que le seuil de l'homme conscient.

On a discuté les facteurs qui peuvent influencer la régulation thermique pendant l'anesthésie chirurgicale; les principaux étaient la réduction du métabolisme basal et la prévention des frissons obtenue en provoquant la relaxation musculaire complète, la création d'un "climat particulier" autour du corps du malade au moyen de champs opératoires, la relation directe qui peut exister entre la capacité de sudation et l'administration de liquides intra-veineux, et la modification des pertes calorifiques pulmonaires par l'emploi de différentes méthodes respiratoires.

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