NORMAL THERMAL PATTERNS IN CORNEA AND PERIORBITAL SKIN*†

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WHILST the absolute value of a surface temperature may have intrinsic value as a measurement, it is of limited application since so many factors are involved in its formation. These include local blood supply, endogenous metabolism, environmental temperature, and the period of equilibration before measurement is made. In practice it is impossible to separate their various effects with any degree of certainty so that any interpretation given to an isolated surface temperature reading is of doubtful value. This contrasts with the measurement of a relatively constant temperature such as that of the body core, since here deviations from normality can be readily detected. However, in man, as surface anatomical symmetry exists about a median plane the temperature of cornea or skin on one side of this plane can be compared with that of a contralateral area and any deviation from normality detected. This pre-supposes that the normal temperature difference has been established and such an assumption is implicit in the literature on surface temperature measurement (*e.g.* Lawson, 1957; Williams, Williams, and Handley, 1960, 1961; Lawson and Chughtai, 1963; Barnes, 1963; Barnes and Gershon-Cohen, 1963; Gershon-Cohen, Berger, Haberman, and Barnes, 1964; Wood, 1964, 1965; Heinz, Goldberg, and Taveras, 1964; Cosh, 1966; Cosh and Ring, 1967), it being assumed that this anatomical symmetry produces a thermal symmetry as between right and left sides. The quantitative data in support of this is scanty; Williams and others (1961) assume a difference of greater than 1°C. over breast lesions to be abnormal but no evidence is given; Gershon-Cohen and others (1964) also use this figure but state that after sufficient studies have been made some other figure may be found more appropriate (in distinguishing benign from malignant conditions in the breast); Cosh (1966) mentions and illustrates the thermal symmetry of the hands giving actual temperatures measured, but this paper is mainly concerned with sequential measurements and not differences; Heinz and others (1964) assume a difference of 1°F. between the right and left halves of the head but offer no evidence in support; only Wood (1965) attempts to establish a normal temperature difference—in this case for forehead skin. Using a Barnes thermograph on approximately 1,000 normal subjects, he found the average temperature difference between the two sides to be 0.5°F., but again only this statement is made and no further data are given. Areas of skin respond differently to changes in environmental and body core temperature according to their anatomical site (Fox and Edholm, 1963). Consequently, a normal difference over, say, breast skin need not necessarily be the same as that over forehead skin. The purpose of this paper is to investigate the temperature differences that exist between right and left corneae and peri-orbital skin, and to determine if a constant thermal pattern exists in an individual at differing environmental temperatures over a period of time.

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Material and Methods

The instrument used for measuring surface temperature is a bolometer (Mapstone, 1968a). Air temperature was measured to the nearest degree centigrade with an air thermistor probe suspended 2 ft behind and in the same horizontal plane as the subject's eyes.

Measurements were made after a 15-minute period of equilibration in a room from which draughts were excluded as far as possible; no radiation from natural or artificial heat sources was allowed to play directly on the subject's face.

Temperature measurements were made over four areas on each side:

- (1) cornea,
- (2) medial forehead skin,
- (3) lateral forehead skin,
- (4) lower lid skin,

and since the separation of the bolometer and surface was approximately 0.5 cm. the surface of which temperature was measured had a diameter of 10 mm. Seventy normal subjects were used for this part of the investigation, which was conducted at environmental temperatures between 18 and 27°C.

The same measurements were made on five subjects (one of whom had had a bilateral cervico-dorsal sympathectomy 18 years ago) at alternately 3- and 4-day intervals spread over an 8-week period. These measurements were made in the late afternoon under the same conditions as described above.

Results

Figs 1, 2, 3, and 4 record the frequency distribution of the temperature differences between right and left corneae, medial forehead, lateral forehead, and lower lid skin

FIG. 1.—Frequency distribution of corneal temperature differences (left minus right).

FIG. 2.—Frequency distribution of medial forehead skin temperature differences (left minus right).

FIG. 3.—Frequency distribution of lateral forehead skin temperature differences (left minus right).

FIG. 4.—Frequency distribution of lower lid skin temperature differences (left minus right).

respectively in seventy normal subjects. The figures were obtained by subtracting the temperature of the right side from that of the left, attention being paid to the sign (plus or minus) of the result. A plot of the cumulative frequency distribution of these differences on normal probability paper produced an approximately straight line, *i.e.* these are normal distributions. Table I records the mean and standard deviation for these four areas; the values are recorded for left side minus right side, numerically they are the same for right minus left but the sign is reversed.

TABLE I
NORMAL VALUES FOR MEAN AND STANDARD DEVIATION OF
TEMPERATURE DIFFERENCES BETWEEN LEFT AND RIGHT SIDES OF THE
FACE AND LEFT AND RIGHT CORNEAE

The figures given are for left side minus right side

Temperature (°C.)	Cornea	Forehead Skin		Lower Lid Skin
		Medial	Lateral	
Mean	-0.05	+0.09	-0.08	+0.06
s.d.	±0.17	±0.23	±0.28	±0.28
Mean ± 2 s.d.	+0.29 -0.39	+0.55 -0.37	+0.48 -0.64	+0.62 -0.5

s.d. = standard deviation

Fig. 5 (opposite) records the absolute temperatures and temperature differences obtained in one of the five subjects; the graphs of the other four differ in no substantial way.

These five subjects gave twenty graphs of temperature differences, and in seventeen of these this difference is constant as regards laterality, *e.g.* in Fig. 5c, the temperature of the lateral forehead skin on the right side is constantly greater (mean 0.42) than that on the left. Occasionally, there occurs a measurement that is not in accord with the others as regards the hotter or colder side; this occurred on eleven occasions out of 578 temperature recordings and served to illustrate the remarkable constancy of the thermal patterns.

On three occasions the temperature differences are irregular as regards sign being positive or negative with no apparent pattern, Fig. 5b illustrates one such. The mean value for these temperature differences was however -0.0058, +0.047, and 0.0°C. respectively; these would not be detected by a bolometer reading to 0.1°C. and so the two areas would be regarded as having equal temperatures. The apparent irregularity as regards which side is hotter (or colder) represents random errors in taking measurement.

From the temperatures recorded the gradients of change in temperature with change in environmental temperature were calculated (Table II, opposite). For the first four subjects these gradients are all similar, both for cornea and periorbital skin, and over the 10°C. range that the recordings were made, the overall mean gradient was 0.13°C./°C. change in environmental temperature. For the fifth subject the overall mean was 0.06°C./°C. change in environmental temperature.

Discussion

Surface temperature as measured with a bolometer (sensitive to infra-red radiation in the range 1 to 25 μ approximately) gives an observed reading (T_o) which is related to the

FIG. 5.—Absolute temperatures and temperature differences obtained in Subject 2.

TABLE II

GRADIENTS OF TEMPERATURE CHANGE PER °C. CHANGE IN ENVIRONMENTAL TEMPERATURE

Subject 5 had had a bilateral cervicodorsal sympathectomy 18 years ago

The detailed graphs of Subject 2 are shown in Fig. 5

Temperature (°C.)		Cornea		Forehead Skin				Lower Lid Skin		Mean
				Medial		Lateral				
Subject No.	1	Right 0.15	Left 0.16	Right 0.09	Left 0.09	Right 0.07	Left 0.10	Right 0.10	Left 0.10	0.11
	2	0.11	0.11	0.16	0.16	0.13	0.17	0.17	0.21	0.15
	3	0.15	0.16	0.11	0.12	0.14	0.18	0.13	0.13	0.14
	4	0.15	0.16	0.09	0.07	0.09	0.09	0.19	0.13	0.12
	Mean 1-4	0.14	0.15	0.11	0.11	0.11	0.14	0.15	0.14	0.13
5	0.06	0.06	0.04	0.07	0.02	0.05	0.11	0.11	0.06	

actual temperature (T_a) by the equation:

$$(T_o)^4 = \epsilon (T_a)^4 \dots \dots \dots (1)$$

where ϵ is the surface emissivity.

This follows from the Stefan-Boltzmann law for black body radiation (Mapstone 1968a).

Let the observed and actual temperatures of cornea or skin on the right and left sides be T_o and T_a and T_o' and T_a' respectively. Then from (1)

$$(T_o)^4 = \epsilon (T_a)^4 \dots \dots \dots (2)$$

$$\text{and } (T_o')^4 = \epsilon (T_a')^4 \dots \dots \dots (3)$$

$$\text{from (2) } T_o = \sqrt[4]{\epsilon} T_a \dots \dots \dots (4)$$

$$\text{from (3) } T_o' = \sqrt[4]{\epsilon} T_a' \dots \dots \dots (5)$$

The observed temperature difference is $T_o - T_o'$ and the actual difference is $T_a - T_a'$; denote the former by x and the latter by y , then from (4) and (5)

$$T_o - T_o' = \sqrt[4]{\epsilon} (T_a - T_a')$$

$$\text{i.e. } x = \sqrt[4]{\epsilon} y$$

If the surface is a black body radiator, $\epsilon = 1$ and $x = y$, if ϵ is less than 1 then there is an error in the observed temperature difference, *e.g.* assume the emissivity of the cornea to be 0.9 then:

$$\begin{aligned} x &= \sqrt[4]{0.9} y \\ &= 0.97 y \end{aligned}$$

In practice this means that, if the true temperature difference were 2°C ., then the observed difference would be $0.97 \times 2^\circ\text{C} = 1.94^\circ\text{C}$., using a radiometer reading to 0.1°C . this error would be just detectable. Even if the true difference were 5°C . the observed would be 4.85°C . Since the emissivity of cornea (Mapstone, 1968a) and skin (Hardy, 1939) is greater than 0.97 and 0.989 ± 0.01 respectively, then the error in measuring temperature differences using this method is negligible.

Measurements were made at four sites on each side of the median plane, the areas together with their major blood supplies are (Fig. 6):

(1) Medial forehead skin, supplied by the supra-orbital and frontal branches of the ophthalmic artery and thus ultimately by the internal carotid.

FIG. 6.—Blood supply to, and site of, areas where measurements were made.

(2) Lateral forehead skin, supplied by the frontal branch of the superficial temporal artery and thus ultimately by the external carotid.

(3) Lower lid skin, supplied by medial and lateral palpebral branches of the dorsal nasal and lacrimal arteries respectively, and by branches of the infra-orbital and transverse facial arteries, *i.e.* both internal and external carotids supply this area.

(4) Cornea, this has no blood supply, but heat is convected to it by the aqueous, which itself is heated by the blood in the anterior segment, *i.e.* the cornea has a "thermal supply" indirectly from the internal carotid.

These four areas were chosen since it was found that in association with ocular disease relatively large fluctuations in temperature occurred in cornea and periorbital skin (Mapstone, 1968c). In addition medial forehead skin temperature reflects events in the internal carotid artery (Wood, 1965), whilst lateral forehead skin (external carotid supply) acts as a control.

In general, skin gains heat from three sources:

- (1) Endogenous metabolic heat.
- (2) Exogenous heat convected by the vascular system.
- (3) "Contiguity" heat conducted from adjacent tissues.

This heat gain is balanced by heat loss which can normally occur only to the external environment. There is no reason to suppose that endogenous heat, contiguity heat, or a change in environmental temperature would affect the right and left sides of the body differently, so that any temperature difference existing between the two sides is largely a reflection of differing blood supplies. Hence to say that one side is constantly hotter than the other is to say that the blood supply to that side is greater. Conditions in the cornea are more complicated, but again any difference between right and left corneal temperatures is largely a reflection of unequal blood supplies, although here the supply is to the anterior uveal tract (Mapstone, 1968b). Whilst these statements are true in essence they need qualification, since Lawson and Chughtai (1963) and Lawson and Gaston (1964) have shown that the venous blood draining a neoplasm or localized inflammatory process can have a higher temperature than the arterial supply, *i.e.* part of the local temperature increase must be due to endogenous tissue metabolism in these instances.

The results in Table I indicate that the mean temperature difference between right and left corneae and periorbital skin is less than $0.1^{\circ}\text{C}.$; the mean $\pm$ two standard deviations gives a value of approximately $0.4^{\circ}\text{C}.$ for cornea and $0.6^{\circ}\text{C}.$ for skin. The interpretation to be given to an isolated temperature difference reading, if greater than normal, is that there is a difference in blood supply to the two sides, either an ischaemia of one or a hyperaemia of the other. This must be qualified, as mentioned above, by the effect of increased metabolic heat that can come from a neoplastic or inflammatory process, but, since these are normally associated with an increased blood supply, it is impossible to separate their effects.

The establishment of normality for a population whilst having useful application, allows a limited interpretation of an individual's isolated temperature difference readings. Relatively large differences occur in patients with anterior uveitis and carotid artery pathology and these may show a sequential change, *e.g.* consider a hypothetical instance of a subject with a temperature difference between say lower lid skin of $+0.4^{\circ}\text{C}.$ (right minus

left), subsequently it is found that the difference has changed to -0.4°C . Both measurements are within normal limits but the overall change has been -0.8°C .; with the evidence available from these two readings no further interpretation is justified.

However, if individuals maintain thermal patterns, then more information can be obtained from temperature differences. There are three possible patterns:

- (1) The right and left sides vary as to which is hotter, there being no defined pattern.
- (2) The right and left sides have equal temperatures.
- (3) The right side is constantly hotter or colder than the left.

If (1) were true then, as mentioned above, a fluctuation of 0.8°C . could occur and yet each reading would be within normal limits. No graphs of temperature difference in the five subjects showed this pattern. In the case of (2), random errors alone would produce small plus or minus variations from a zero difference, but the mean difference over a period of time would be 0.0°C . or a value less than the sensitivity of the bolometer; Fig. 5*b* illustrates this, as did two other temperature difference graphs. The third possibility, that one side is constantly hotter or colder than the other, is shown by the remaining seventeen difference graphs. The existence of these patterns allows a test of statistical significance to be applied to a sample of readings, *e.g.* in Fig. 5*d* the mean and standard deviation of the seventeen sample differences for lower lid skin is $+0.38^{\circ}\text{C}$. and $\pm 0.167^{\circ}\text{C}$. respectively. If subsequently a second set of sample differences (say seventeen) was obtained and the standard deviation of this sample remained the same as for the first, then application of Student's* "*t*" test shows that a change in sample mean of greater than $\pm 0.17^{\circ}\text{C}$. is highly significant ($P < 0.01$). If such a change in mean value did occur, then a valid interpretation would be that the conditions under which measurement was made were not the same in the two samples. As environmental temperature can be controlled, the cause of the change in mean value probably lies in the subject and, further, if disease is present it can be ascribed to this. The information to be gained from a sample is then greater than from an isolated temperature difference measurement. The relevance of this to anterior uveitis and carotid artery pathology will be shown in subsequent papers.

The measurement of surface temperature, using either a direct recording instrument or an infra-red imaging device, has lately produced information of diagnostic, prognostic, and therapeutic value (see references in the introduction). If such measurement is to be routinely used in clinical medicine, then strict control of the environment will have to be excluded. For this reason the environmental conditions were deliberately kept simple and temperature fluctuated over a 10°C . range. The effect of this is shown in Table II which records the change in surface temperature per degree change in environmental temperature. This shows that the right and left sides of an individual change in similar degree so that a temperature difference measured at one environmental temperature will remain the same at another. Whilst these results apply to areas of normal cornea and skin, Williams (1964) in carcinoma of the breast and Wood (1965) in carotid artery stenosis have shown that, in the presence of unilateral disease, a temperature difference is decreased as the patient is warmed, but with local cooling a difference is accentuated. Changes in ambient temperature would also be expected to have a similar effect. There are three main aspects to this problem, *viz.* the superficial blood vessel response to changes in ambient temperature, the net quantity of heat lost by radiation and convection to the environment, and the rate of flow of blood and hence heat into the tissue.

* No correlation between sample means is assumed; in practice it would be necessary to allow for this and amend '*t*' accordingly.

The importance of the first factor is illustrated by the following example: in the presence of unilateral inflammatory disease the superficial blood vessels on the ipsilateral side will not respond as do normal vessels to changes in environmental temperature, *i.e.* as ambient temperature falls normal vessels will in general vasoconstrict whereas inflamed vessels will not, hence a temperature difference will be accentuated; conversely, as ambient temperature increases the normal side will show a vasodilatation, whereas on the contralateral side the inflamed vessels are already maximally dilated, hence a temperature difference will be diminished. A change in environmental temperature can affect skin blood flow in four main ways:

- (1) Variations in vasoconstrictor tone.
- (2) A vasodilator response occurring in areas containing sweat glands, the dilatation being produced by a bradykinin release mechanism (Fox and Hilton, 1956, 1957, 1958).
- (3) The effect of local skin cooling—a vasoconstriction.
- (4) The effect of local skin heating—a vasodilatation.

The first two represent the result of a total body response to changes in ambient conditions, whereas the last two are purely local phenomena.

Areas of skin respond differently according to their anatomical site and whilst limb skin blood flow has been extensively investigated the reactions of periorbital skin have been largely neglected. The available evidence indicates that forehead and cheek have little vasoconstrictor control but do have a vasodilator mechanism (Blair, Glover, and Roddie, 1960; Fox, Goldsmith, and Kidd, 1962), whilst the effect of local cooling on forehead skin produces little vasoconstrictor response (Hertzman and Roth, 1942; Froese and Burton, 1957). If, therefore, extremes of environmental temperature are avoided, *i.e.* sweat vasodilatation and vasoconstriction do not occur, then the magnitude of a temperature difference between the normal and abnormal side will not be affected. In practice, this means that at ambient temperatures of approximately 18 to 24°C. quantitative comparisons and deductions can be made from sequential difference measurements.

The response of uveal blood vessels—and hence of corneal temperature differences—to changes in ambient temperature are unknown. Schwartz (1965), on the basis of experiments done on rabbits, concluded that the vascular component of the eye vasoconstricts. He measured the temperature of ocular tissue in different animals along an antero-posterior axis from cornea to orbit at varying environmental temperatures, and plotted the pooled results against environmental temperature. Whereas cornea showed a linear fall in temperature, other ocular tissues showed initially a steep drop which subsequently became almost linear. However, all these graphs begin from one measurement made on one rabbit whose rectal temperature was higher than that of any other, *i.e.* this was a “hot” rabbit, which factor alone would raise the temperature of its eye. If the readings obtained from this animal are ignored then the curves fitting the remaining points as drawn by visual inspection approximate to a straight line, and the vasoconstrictor interpretation is invalid. From a teleological aspect too, any marked vasomotor response on the part of the uveal blood vessels would be disastrous to the function of the eye, and since retina is but ectopic brain the constancy of its thermal environment is of paramount importance. To this end the arrangement of the uveal blood vessels exhibits a superb counter-current heat exchange mechanism, the cold venous blood returning from the anterior segment being heated by the arterial blood passing anteriorly, which latter is itself placed between the veins and retina. Further, before the macula is reached, the venous blood has already made its exit from the

eye *via* the vortex veins so that this part of the retina can be but rarely exposed to a severe thermal stress.

The effect on a temperature difference of net heat loss and rate of blood flow in unilateral disease are closely linked. If the only variable between the two sides were absolute surface temperature then, since the differences measured are small, both sides would lose similar quantities of heat and the measured difference would not vary with environmental temperature. If, however, one eye were ischaemic then there would in unit time be less blood flow and less heat brought to that eye than to the fellow normal eye. This being so the rate of fall and rise in temperature with ambient changes will not be the same on the two sides so that the difference measured will also depend on the time spent in equilibrating to a new environmental temperature.

The measured difference in the presence of unilateral disease is therefore dependent on numerous variables, but if ambient temperatures are maintained between approximately 18 and 24°C. then sequential measurement and interferences therefrom are valid as regards cornea and periorbital skin.

Summary

The temperature difference between right and left corneae and periorbital skin is normally no greater than 0.4 and 0.6°C. respectively.

Two thermal patterns are shown by normal subjects: either one side is constantly hotter or colder than the other, or no temperature difference exists (within the limits of instrument sensitivity). The existence of these patterns allows tests of statistical significance to be applied to sample differences.

The effect of fluctuations in environmental temperature over a range of 10°C. on the magnitude of a temperature difference between corneae and periorbital skin is negligible in normal subjects.

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