OBSERVATIONS ON THE TEMPERATURE OF THE HUMAN RECTUM

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Bernard's concept of the *milieu intérieur* was a vital step in our understanding of the human body. It is fundamental to realize that much of our biological activity is concerned in the maintenance of the so-called internal environment. But it is becoming increasingly clear that a rigid approach to the body constants which constitute this internal environment is no longer wholly acceptable. Such standards as blood pressure, once the inflexible index of an individual's circulatory health, are labile to a degree which even now is insufficiently realized.

The present paper is concerned with body temperature, another so-called "body constant" which displays great elasticity. For tissue temperature varies not merely with the general heat equilibrium of the body but also with the organ under consideration, with its anatomical location, its functional activity, and, in many cases, with the state of its circulation.

Recent observations show that a temperature gradient exists between the surface layers and the deep structures in the extremities. Moreover, the temperature of resting muscle is very much lower than either rectal or mouth temperature (Barcroft and Edholm, 1946). Thus in the uncovered resting forearm deep muscle temperatures as low as 30.7° C. were commonly found, with subcutaneous temperatures of 28.5° C. and skin temperatures of 27.9° C. Even when covered, the deep muscle temperature was only 36.2° C.

The work of Bazett and his co-workers (Bazett, Mendelson, *et al.*, 1948) has demonstrated, further, that the temperature of the blood in the brachial and radial arteries is far lower than had hitherto been assumed, temperatures as low as 31° C. having been recorded from a radial artery in a human forearm not particularly cold to the touch. Bazett postulated "pre-cooling" of the artery and its contents by the accompanying venae comites carrying cold blood away from the fingers. It is abundantly clear, therefore, that the tissues of the extremities can no longer be regarded as functioning in an environment approximating in temperature to that of the rectum, and it seems unlikely, in the resting state, that skeletal muscle is of much importance in heat production.

Unpublished observations on ten cases made jointly with Professor F. H. Bentley fully confirm these findings. They suggest, moreover, that the temperature of other extraperitoneal organs is also below that in the peritoneal cavity. Thus, in one unclothed individual the temperature of the toes was 20° C.; that of the deep thigh muscles was 35.2° C.; the temperatures of the deep abdominal musculature and of the renal pelvis were 36.4° and 36.8° C. respectively. The temperatures in the regions just deep to the peritoneum and in the rectal ampulla were both 37.1° C. Similar distributions of temperature were found in all cases examined.

It has therefore been suggested that the temperature of an organ depends in part upon its depth below the skin

and in part upon its anatomical relation to the abdominal cavity. Yet, even in the abdominal cavity itself, temperatures vary with the organ concerned and the state of its functional activity. Wiggers and Orias (1932) have shown clearly that liver temperature in the dog is about 1° C. above all other intraperitoneal temperatures. Federov and Shur (1942) showed, too, that in the dog the lowest intraperitoneal blood temperatures were to be found in the abdominal aorta, whereas the highest were in the hepatic vein. They demonstrated that increased metabolism exaggerated this difference. The evidence strongly suggests that the principal sources of body heat in the quiescent subject are intraperitoneal and it may well be, as suggested by Federov and Shur, that the organs concerned are the liver and, to a less extent, the intestines.

Heat production in the body would appear, then, to be considerably more centralized than has often been assumed. Also when one remembers the role of the skin as a radiator of heat, it is not surprising that the temperature of a peripheral organ varies directly with its proximity to the peritoneal cavity and inversely with its depth below the skin. But other factors are equally important in determining tissue temperature. Whereas the influence of local heat production in resting extraperitoneal organs is small, the state of the circulation is of prime importance. The temperature of the digits, for example, may vary in normal individuals exposed to a room at about 18° C. from about room temperature to 35° C. or over, according to the presence or absence of cutaneous vasodilatation. The effect of the circulation on temperature is, of course, less marked in the proximal parts of the limb, but, even here, in deeply situated muscle, it is the factor of increasing blood flow which is largely responsible for the rise in temperature which occurs during moderate exercise (Barcroft and Millen, 1939).

It is evident that there is no one measurement which can fairly be called "body temperature." The best that can be hoped for is a compromise which will indicate roughly the balance between heat production and heat loss in the body. In this respect the temperature of the rectum has long occupied a position almost sacrosanct. Of all the readily available measurements this is the one which above all others has been regarded as an accurate indication of the thermal equilibrium of the body.

Recent observations have, however, made it clear that rectal temperature does not always behave as might be expected. The work of Bazett, Love, *et al.* (1948) has shown that the temperature of the terminal few inches of the rectum may be influenced directly by venous return from the lower limbs. Even allowing for this source of error, peculiarities have been observed. As long ago as 1778 Leslie reported that immersion of the body in cold water frequently caused a rise in temperature. Bazett, Love, *et al.* (1948) reported similar findings. Kerslake and Cooper (1950) showed, too, that exposing the body to heat may conversely produce a fall in body temperature. The rise which follows immersion in cold water has been explained as possibly being due to reflex vasoconstriction in the skin, resulting in a reduction of heat elimination and a consequent warming of the body by the continued heat production. In Kerslake and Cooper's experiments, in which the trunk was heated and the hands were left exposed to the room air, the fall in rectal temperature might also be explained as being due to the vasodilatation in the skin of the hands and a consequent increase in heat elimination.

It is the object of this paper to demonstrate that these explanations cannot be complete, and that the temperature of the rectum—like the temperature of peripheral organs—can be affected by the blood flow through it.

Methods

The observations leading to the present investigation were first made during experiments which primarily concerned the responses of the skin circulation to environmental temperature changes. The findings of Leslie and of Kerslake and Cooper, referred to above, were fully confirmed. Thus, cooling the body produced a rise in rectal temperature, warming the body a fall. Simultaneous records of skin and of rectal temperature, however, suggested that the rectal-temperature changes were frequently too rapid and too similar in timing to the vasoconstriction and the vasodilatation which took place in the skin to be the simple result of altered heat-balance.

To investigate the matter further, a more delicate measurement of rectal temperature was used, together with observations of blood flow in the rectum. Rectal temperature was measured thermo-electrically, using copper-constantan thermocouples, a delicate moving-coil mirror galvanometer, a slit-lamp, and scale. The movements of the light on the scale were recorded continuously on a kymograph by means of a manually operated mechanical device (Schmidt and Pierson, 1934). Temperature changes of 0.001°C . could be accurately detected.

Blood-flow changes in the rectum were measured by using the heated thermocouple blood-flow recorder described previously (Grayson, 1951b) and derived from the instrument first described by Gibbs (1933). It consisted of a small mass of copper about 1 mm. in diameter, which could be heated by the passage of an electric current through a fine attached filament of constantan wire. A copper-constantan thermojunction, also joined to the copper sphere, was connected to a simple thermo-electric circuit consisting of a second thermojunction (the cold junction), a moving-coil mirror galvanometer, and a resistance. Heat applied to the recording couple produced a flow of current (measured by means of the galvanometer), which in accordance with thermoelectric principles was directly proportional to the temperature difference between the recording and cold junctions. In the present experiments the copper sphere, with its attached thermojunction and leads supplying the heater filament, was inserted $6\frac{1}{2}$ in. (16.5 cm.) past the anal orifice and lay in the ampulla of the rectum. The cold junction was also inserted rectally. Current was passed through the heater sufficient to raise its temperature 2°C . above that of the cold junction. Both heated couple and cold junction were equally affected by genuine alterations in body temperature, but an increase in rectal blood flow was shown to cool the relatively hot heated thermocouple; a decrease in rectal blood flow permitted it to warm up further. These changes produced measurable galvanometer deflections and, subject to limitations which will be fully discussed elsewhere, the apparatus provided reliable records of rectal blood-flow change (Grayson, 1951b).

Results

Many of the observations described below were made in the course of other investigations, primarily concerned with the effect of environmental temperature on the cutaneous and visceral circulations. It is not the present

purpose to consider the physiological implications of the blood-flow findings, but simply to relate the temperature of the rectum to vascular events in the bowel.

Effect of Increasing External Cold Stimulus

Cold stimulus at the surface of the body was increased by exposing the abdominal wall of a fully covered subject to the room air at about 18°C . or by immersing the right hand and forearm in water at 7° to 9°C . Both stimuli have been previously shown to produce vasodilatation in the intestine (Grayson, 1950). In the four experiments shown in Fig. 1 the blood flow in the

FIG. 1.—Temperature and blood-flow changes in human rectum of four subjects. The effect of cold stimulus—exposing the abdomen to the room at 18°C . The blood-flow records were taken using the heated thermocouple recorder. Upward movements denote increased flow, downward movements decreased flow. Tracings from original kymograph records. Time base = 30-second intervals.

rectum was recorded by means of the heated thermocouple. It will be seen that in every case an increase in flow occurred, accompanied by a rise in rectal temperature. Where skin temperatures and blood pressures were also recorded, cutaneous vasoconstriction and a variable rise in blood pressure always followed the cold stimulus (Fig. 3 A). After the cessation of the stimulus, the rectal temperature, rectal blood flow, skin temperature, and blood pressure returned to resting levels. In every case the changes in rectal temperature were coincident with the changes in rectal blood flow. In a series of 25 experiments the rise in rectal temperature varied from 0.05° to 0.5°C .

Owing to the fact that the technique for measuring rectal blood flow was not quantitative it was impossible to determine whether the rectal temperature changes could be related to the extent of the blood-flow change.

To counter the possibility that venous return from the lower limbs might influence the results, the experiments were repeated with the circulation from the lower limbs occluded. Pressure cuffs around the thighs were inflated to 200 mm. Hg and the patient's left arm was placed in cold water. Cold stimulus still produced vasodilatation in the rectum accompanied by an increase in rectal temperature.

Effect of Decreasing Cold Stimulus

In 15 experiments the subject was initially exposed to the room air at 18 – 20°C . After the rectal temperature and blood flow reached equilibrium, cold stimulus was

FIG. 2.—The effect on rectal temperature and rectal blood flow of removing cold stimulus from the body surface. Subject initially exposed to room air at 18° C.

removed from the body surface by covering with blankets. This procedure has been shown to produce vasodilatation in the skin (Grayson, 1951a) and vasoconstriction in the bowel of normal individuals (Grayson, 1949). In the present experiments blood flow in the rectum was recorded, using the heated thermocouple recorder. The temperature of the rectum and, in some cases, skin temperature from the periphery were also measured, using independent thermocouples. In Fig. 2 are shown the results of a typical experiment in which a fall in rectal temperature accompanied the fall in rectal blood flow. In all experiments the time relation-

FIG. 3.—A comparison between rectal and skin temperatures. A. Cooling the surface of the body. B. Warming the surface of the body.

ships of the rectal temperature changes corresponded exactly with those of the rectal blood-flow changes.

Fig. 3 B shows the results of a typical experiment in which the skin temperature and the rectal temperature were recorded simultaneously. Again it will be seen that the rectal-temperature changes closely followed the skin-temperature changes.

Effect of Intravenous Adrenaline on Rectal Temperature

In the experiments described above the bowel blood-flow changes were always accompanied by cutaneous blood-flow changes which were directionally opposed. A close consideration of the time relationships will be shown largely to discount the view that the cutaneous vascular changes could alone account for the changes in rectal temperature. None the less, it would have been desirable to employ a stimulus affecting the bowel circulation alone. Unfortunately, no such stimulus has been

FIG. 4.—Effect of intravenous adrenaline tartrate—5 μ g. a minute—on rectal temperature and blood flow. Tracing from original kymograph record. Rectal blood flow recorder.

discovered. Indeed, in my view, alterations in blood flow in any organ must inevitably be accompanied by general circulatory adjustments. The intestinal vascular responses studied to date have been largely secondary to primary skin changes, but even bowel blood-flow changes which have been observed to occur in response to primarily intestinal stimuli are accompanied by cutaneous vascular changes.

Intravenously administered adrenaline, however, is a stimulus which produces the same type of change in the intestinal vessels as in the skin, causing vasoconstriction in both (Grayson and Swan, 1950). Thus it might be expected that if the rectal-temperature changes were due to an interference with the heat loss there would be a rise in rectal temperature, the more so in view of the stimulatory effect of adrenaline on metabolism.

In the experiment shown in Fig. 4 adrenaline was infused intravenously at the rate of 5 μ g. a minute for five minutes, using a constant-speed infusion apparatus. It will be seen that a fall in bowel blood flow occurs as described previously (Grayson and Swan, 1950) accompanied by a fall in rectal temperature of 0.2° C. Similar

results were obtained in three other experiments, the rectal temperature drops being 0.15° , 0.2° , and 0.23° C. during five-minute infusions.

Discussion

In the experiments just described, vascular changes in the large intestine were often accompanied by temperature changes in the rectum. It must be remembered, however, that intestinal blood-flow changes are rarely, if ever, strictly localized. In most of the experiments which I have performed intestinal vascular changes have been a secondary result of cutaneous blood-flow changes. Thus intestinal vasodilatation was the result of cutaneous vasoconstriction and intestinal vasoconstriction was the result of cutaneous vasodilatation. It might be argued, therefore, that in most cases the changes in rectal temperature were true indications of a change in the heat equilibrium of the body and that the apparent relation to intestinal blood flow was purely coincidental.

Even without considering the experiments in which adrenaline was used it does not seem likely that this argument can be completely true. Most of the experiments described were short. The rise in rectal temperature was as rapid as the rise in rectal blood flow. Furthermore, when the stimulus was withdrawn the return of rectal temperature to resting levels was as complete and rapid as the return of the rectal blood flow to resting levels. Again, in Fig. 3 it will be seen that the changes in rectal temperature began at practically the same time as the changes in skin temperature. It seems unlikely that changes in heat balance could be so rapid or could so accurately follow the changes in intestinal flow.

The experiments in which adrenaline was used confirm that rectal temperature can be raised or lowered by increasing or diminishing the blood flow. In so far as the action of adrenaline is to produce cutaneous vasoconstriction and increased metabolism it might be anticipated that, if anything, the general body temperature would rise. In fact, as has been shown, adrenaline administered for a short period produces a slight fall in rectal temperature accompanying a diminution in rectal blood flow. It must be concluded, therefore, that the rectal temperature itself, like the temperature of more peripheral tissues, can be affected directly by blood-flow changes.

This implies, further, the existence of a temperature gradient between the rectum and the afferent blood. Thus, in some subjects, changes of up to 0.5° C. were produced in rectal temperature by purely circulatory stimuli. The temperature of the blood supplying the rectum in these individuals must have been more than 0.5° C. higher than the resting rectal temperature. Therefore, although the observations of Bentley and Grayson, already referred to, showed that the rectal temperature was as high as the temperature immediately beneath the peritoneum, temperature gradients of the type described in other species by Wiggers and Orias and by Federov and Shur must exist in the peritoneal cavity of the human subject.

In conclusion it should be emphasized that the changes in rectal temperature with which we have been concerned were usually small in relation to the wide variation met with clinically and even physiologically. It is not claimed that blood-flow variations seriously affect the clinical interpretation of rectal-temperature changes. The present work simply demonstrates that rectal

temperature, albeit a useful clinical indicator, is not truly representative of the temperature at which the body's tissues function. The fact that it can be affected by blood-flow changes demonstrates that it is not even the highest temperature in the body; it is simply one stage in the temperature gradient which exists between the organs of heat production and the organs of heat dissipation.

Summary

The simultaneous recording of rectal temperature and rectal blood flow showed that external stimuli of heat and cold caused changes in rectal temperature coincident with the changes in rectal blood flow.

Intravenous adrenaline produced diminution in rectal blood flow, skin temperature, and rectal temperature.

The evidence is regarded as indicating that intestinal blood-flow changes can cause changes in rectal temperature analogous to the changes produced in skin temperature by changes in skin blood flow.

It is argued that the temperature of the blood flowing to the rectum must, in some subjects at least, be considerably higher than the actual temperature of the rectum.

This work was performed during the tenure of a British Medical Association Research Scholarship. I am indebted to Professor F. H. Bentley and to Professor R. J. Brocklehurst for their interest and advice.

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A report in the *New York Times*, November 26, describes the progress being made towards the control of chemicals in foodstuffs in the United States. A Congress Select Committee of seven members has been meeting regularly for about a year to hear evidence from people in medicine and industry, and hopes to be able to issue a report with recommendations after its final hearings in New York in January. At its recent sessions in Los Angeles it considered insecticides and heard a pathologist report that in 19 out of 20 routine post-mortem examinations traces of chlorinated hydrocarbon insecticides were also found in the bodies when the appropriate chemical tests were made, although in no case was the cause of death poisoning by insecticide. Chlordane was very dangerous anywhere near food, but parathion and D.D.T. were without risk. The committee also considered risks from oestrogenic hormones. No evidence was found that these substances were harmful used in cosmetic face creams, but their use in caponizing poultry was potentially dangerous. Birds for sale in the poultry market as food had been found to contain as much as 15 mg. unassimilated stilboestrol—seven times the human dose. (These capons are eunuchoid cockerels which have been treated with female hormones by subcutaneous implantation of a tablet to make them fatter and their flesh softer and juicier. A cockerel starting treatment at 9 weeks old may weigh half a pound more and require 6% less food at 20 weeks—eating time—than a control untreated bird.)