SPECIAL ARTICLES

ON THE ELIMINATION OF HEAT FROM NORMAL AND PATHOLOGIC SUBJECTS AS DETERMINED FROM CALORIMETRIC STUDIES OF THE EXTREMITIES

SOME years ago Stewart[1] made a study of the circulation in man, dealing almost entirely with blood flow in the hands and feet of both normal and pathologic subjects. In his writings he states that "the quantity of blood in grammes flowing through the hand in the time of the experiment is given by

$$Q=\frac{H}{T-T_1}\cdot\frac{1}{S}$$

in which Q is the quantity of blood, H the heat given off by the blood, T the temperature of the venous blood and S the specific heat of the blood."

I do not believe that the Stewart equation nor any similar equation can be applied correctly to the determination of blood flow. Calorimetric data *per se* can be used only for the determination of heat elimination. And, in turn, the elimination of heat from an extremity is dependent not only on the rate or quantity of blood flow, but also upon various conditions of the blood vessels and radiation factors, namely: (1) Dilated or constricted capillaries or peripheral blood vessels, (2) the number of capillaries functioning, which microscopic studies show varies considerably in different individuals[2] and (3) the capillary blood flow.

The well-known equation for heat conduction is

$$Q=K\,(T_1-T_2)\frac{A}{D}\,t$$

in which Q is the quantity of heat in calories conducted from the extremity to the calorimetric bath in a given time t; K is the conductivity constant; T_1 and T_2 are, respectively, the temperatures of the two bodies; A is the area over which the conduction of heat from one medium to another takes place; D is the thickness and vascularity of the conducting layer.

It is also well known that the heat taken up by the calorimeter can be found from the equation

$$H=(m+m_w)\ (T_3-T_2)$$

in which H is the heat in calories developed in the calorimeter of water equivalent m_w containing a mass of water m, while T_3-T_2 represents the rise in temperature during the time t.

The temperature of the arterial blood in the extremities varies slightly in different cases. Stewart considered 36.7° C. as being a sufficiently exact value. I have taken 37° C. as being, in general, satisfactory since the conclusions reached are not modified by assumptions of a slightly higher or lower amount.

The increase of temperature of M grams of water (*m* grams of water and m_w the water equivalent) is

$$\frac{Q}{M}=\frac{H}{m+m_w}=K_1\frac{\Delta T}{M}\cdot t$$

in which $\Delta T=37°-T$, T° Centigrade being the temperature of the calorimeter and contents at any given time t; or

$$\frac{Q}{M}=K_2\ (37°-T)t$$

in which $K_2=K_1/M$

The rate of increase of the temperature of the immersion bath—which also represents the rate of elimination of heat from the extremity—is given as

$$\frac{dT}{dt}=K_2\ (37°-T)$$

From this equation, by integration, we finally obtain

$$-\log_{10}(37-T)=K_3t+C$$

If T_1 represents the temperature gradient (37° − T) of the extremity (ΔT_1) at time t_1 and T_2 the corresponding value of the temperature gradient (ΔT_2) at time t_2, then

$$K_3=\frac{1}{t_1-t_2}\log_{10}\frac{T_2}{T_1}$$

This equation is the fundamental one involved in calorimetric studies of the extremities, and from the determination of K_3, the rate of transfer of heat from an extremity immersed in a water bath, it is possible to establish certain conclusions of physiological and medical importance.

Applications of the foregoing equation to the data obtained by Stewart demonstrate quite conclusively that there is no evidence of the marked increases in blood flow with time of immersion in the calorimeter which Stewart believed to be present in both normal and pathologic subjects. There is, furthermore, no evidence of any change in the rate of blood flow in any given subject under the conditions of experimentation laid down, provided there is included in the definition of the term "blood flow" the various factors which may affect it or which are the equivalent of such flow.

The conclusions drawn from these studies are:

(1) Calorimetric methods and data can not be used to determine the quantity or rate of blood flow.

(2) Only quantities of heat (Q) and rates (K_3) of transfer of heat can be determined in such calori-

[1] Stewart, "Harvey Lectures," pp. 80–149, 1912–13; "Heart," pp. 33–88, 1911–12.

[2] Sheard, SCIENCE, LX, p. 409, 1924; Brown, "*American Annals of Clinical Medicine,*" I, p. 69, 1922; Brown and Giffin, *American Journal of Medical Sciences,* V, 166, p. 459, 1923; Sheard and Brown, *Journal Laboratory and Clinical Medicine,* X, p. 925, 1925; and Krogh, "Anatomy and Physiology of the Capillaries," Yale Press, 1922.

metric investigations, in which a temperature gradient exists between the immersed extremity and the calorimetric bath.

(3) The equation of conduction of heat

$$Q = K(T_1 - T_2)A/D \,.\, t$$

is applicable to calorimetric studies of the extremities.

(4) The rate of increase (K_3) of the temperature of the calorimeter and contents due to the peripheral or surface circulation is given by the expression

$$K_3 = \frac{1}{t_1 - t_2} \,.\, \log_{10} T_2/T_1$$

(5) Analyses of the experimental results made by the use of this equation, in which $\log_{10} \Delta T$ is plotted as ordinate relative to the time, t, as abscissa, show that there are two distinct portions: (1) that given by the transfer or elimination of heat by virtue of the temperature gradient existing between the foot and the calorimetric bath due to the inherent heat capacity or *tissue heat* of the extremity plus the effects due to surface circulation and (2) that given by the transfer or elimination of heat due solely to *circulatory conditions at or near the surface.*

(6) From a study of normal persons under various conditions of environmental temperature and under the régime of experimentation which has been adopted, there is evidence that (1) the rate of transfer or elimination of heat due to the surface or peripheral circulation *per se* is very approximately directly proportional to the temperature, in degrees Centigrade, of the surrounding environment; (2) the inherent thermal capacity of the superficial or surface layers of the extremity increases proportionately to the square of the temperature in degrees Centigrade of the surrounding atmosphere or environment, and (3) when the temperature of the surrounding environment reaches approximately 15° C. the rate of transfer of heat from the exposed surface of a resting human body becomes negligibly small, as is indicated by the value of the rate of elimination of heat due to the existing conditions of surface circulation.

(7) A comparison of data on the inherent thermal capacities of extremities in normal subjects, in cases of polycythemia and of thrombo-angiitis obliterans (Buerger's disease) shows that there is but little difference in general between that in normal subjects, and that in cases of polycythemia, but that there is a marked difference between the values in Buerger's disease and those obtained in normal subjects.

(8) A study of the rates of elimination of heat at the surface of an extremity due to conditions of surface circulation indicates that this rate of heat elimination may be from two to five times as great in cases of polycythemia as in the normal subjects under similar environmental temperature and, again, about half as great in cases of thrombo-angiitis obliterans (Buerger's disease) as in normal subjects.

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CHROMOSOME VIII IN MAIZE

THE *Pr pr* factor pair, which modifies aleurone color in maize from red to purple, has long been known and has been used extensively in linkage studies. All the published data as well as my own unpublished results indicate that this factor pair does not belong to any of the seven linkage groups in maize which have already been reported. At least five factor pairs, of which four are new and have not previously been described, have been found by the writer to be linked with the *Pr pr* factor pair. A brief description of each of these factor pairs as they are expressed in the soma follows:

(1) *Bm bm,* a factor pair, which, when homozygous recessive, causes a water-soluble, yellowish-brown pigment to develop in the cells of the midrib and sheath of the leaves. This character comes into expression when the plant is about six weeks old and persists throughout the remainder of the life of the plant. This linkage relation was first observed in the summer of 1923. Backcross data from plants grown in 1925 substantiated this linkage and showed a crossing over value between *Pr* and *Bm* of 20 per cent.

(2) Sc_1 sc_1, a factor pair for scarred endosperm, as described in the University of Missouri Agricultural Experiment Station Research Bulletin 52.

(3) Fi_2 fi_2, a factor pair for a fine striping of the chlorophyll, which appears in young seedlings and persists through the life of the plant. The character expression varies from a pure albino, on the one hand, to a nearly green plant, on the other, with plant vigor roughly proportional to the amount of chlorophyll bearing tissue.

(4) *Yg yg,* a factor pair, which, when homozygous recessive, causes the seedling as well as the growing plant to be distinctly yellowish-green in color, due to a deficiency in the chloroplastid pigments. As these plants approach maturity, it becomes increasingly difficult to distinguish them from normal green plants.

(5) *Tn tn,* a factor pair, which, when homozygous recessive, produces a small slender plant with a usually very small ear shoot, a small unbranched tassel, and leaves which are always strongly tinged with anthocyanin.

This group of linked factors is especially interesting in that it represents a new chromosome in maize, to be designated as chromosome VIII.

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