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Temperature and Blood Flow in Extremities Immersed in Water.*

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The present report contains data on the surface temperature of the hand immersed in water of various temperatures. The findings are discussed in relation to the blood flow through the hand.

Procedure. The subjects of these experiments sat in a controlled temperature room with one hand immersed in water until it was certain that thermal equilibrium had been established between the hand and the water as judged by skin temperature measurements. Observations were made at different room temperatures (16, 24, and 32°C) and at several water temperatures (5, 10, 15, 20, and 25°C).

Method. Skin temperatures of the naked hand immersed in water are difficult to evaluate. For this reason, the hand was encased in two rubber (surgeon's) gloves. Thermocouples (T_1) were placed in the medial aspect of the hand and on the lateral aspect of the first phalanx of the index finger. A second set of thermocouples (T_2) was placed directly over these after the first glove had been put on. And a third set (T_3) was similarly placed on the second rubber glove. A set of readings obtained at equilibrium over the finger under conditions where the difference between skin and water temperature was very great follows: T_1, 11.7; T_2, 8.7; T_3. 6.0; and T water, 5.0°C. From these readings it may be estimated that the true skin temperature is of the order of magnitude of 1°C above the value given by T_1. When skin and water temperatures are more nearly equal, the error in assuming T_1 to be the true skin temperature is correspondingly less. For the present purpose, no serious error is introduced if T_1 is regarded as the actual skin temperature.

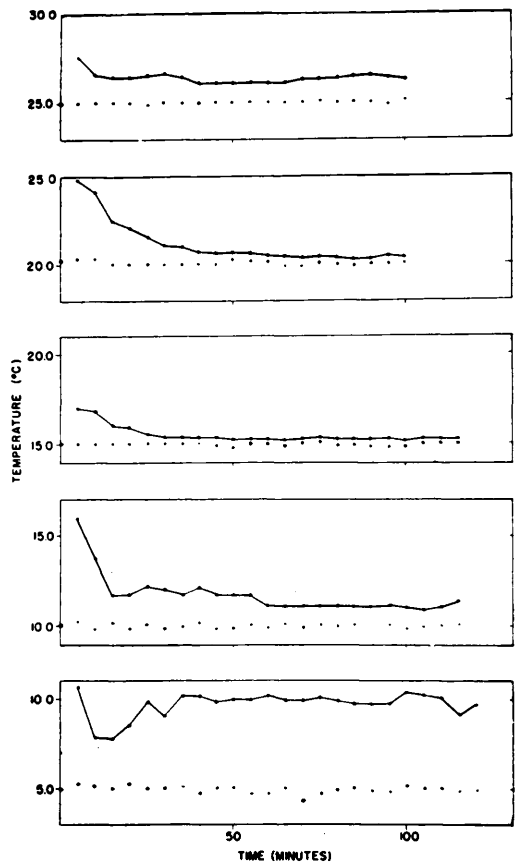

FIG. 1.

Finger skin temperature (solid lines) and water temperature (dots) plotted against time. These data were obtained on one subject who was studied at the 5 different water temperatures indicated. Room temperature was 16°C.

Results. Fig. 1, which shows a typical set of skin temperature measurements obtained on one subject, is given to illustrate the nature of the temperature data obtained. The minor fluctuations in skin temperature that occur in this subject are found with most subjects. In some they are more prominent. The figure also illustrates the fact that the difference between skin temperature and water tempera-

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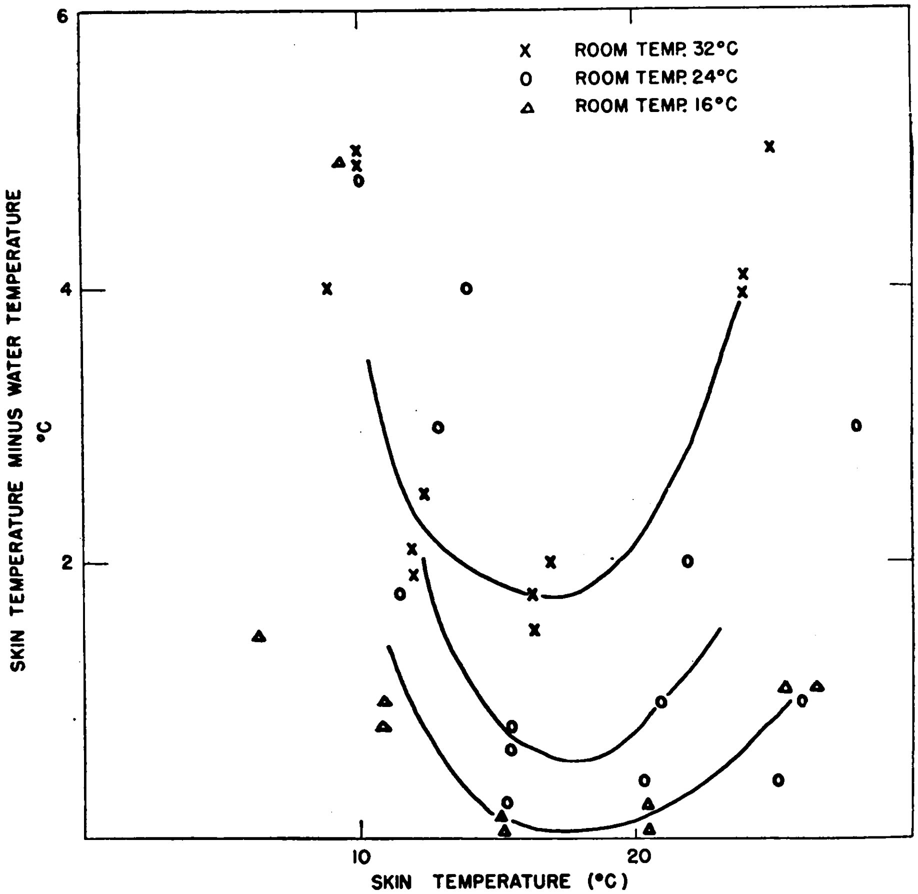

FIG. 2.

The difference between equilibrium finger skin temperature and water temperature, obtained from data such as are shown in Fig. 1, plotted against finger skin temperature. Data were obtained at room temperatures of 16°C (2 subjects), 24°C (3 subjects), and 32°C (3 subjects).

ture is least when the hand is immersed in moderately cold water.

In Fig. 2 the difference between skin and water temperature, obtained from data similar to those given in Fig. 1, is plotted against skin temperature. Data on 8 subjects studied at room temperatures of 16, 24, or 32°C are included. The figure illustrates the fact that the difference between skin temperature and water temperature becomes minimal at moderate temperatures. It also shows the effect of ambient air temperature. These data are for the finger; the data obtained on the hand are similar.

Discussion. The temperature difference between water and skin may be used as a measure of the comparative rates of heat loss from the hand at different water temperatures. For the subject of Fig. 1, these are 4.8, 0.9, 0.3, 0.3, and 1.1 for water temperatures of 5, 10, 15, 20, and 25°C respectively. Since equilibrium conditions exist, these are also the comparative rates of heat supply to the hand.

The rate of heat supply per unit volume of blood is proportional to the temperature difference between the blood entering the hand and the blood leaving it. The former may be taken to be 37°C. The temperature of the blood leaving the hand cannot differ greatly from the temperature of the hand surface, for the deep temperature of extremities immersed in water of a wide range of temperature has been shown not to differ greatly from surface temperature. Barcroft[1] has recently reported on this.

The quantities of heat supplied per unit volume of blood are then roughly proportional to 27, 26, 22, 17, and 11 for water temperatures of 5, 10, 15, 20, 25°C respectively. Dividing the comparative figures for the rate of heat supply to the hand by the comparative figures for the heat supplied per unit volume of blood gives the following comparative figures for blood volume flow: 0.18, 0.03, 0.01, 0.02, and 0.10 for water temperatures of 5, 10, 15, 20, and 25°C respectively.

The above calculations involve assumptions used in the calorimetric method for determining blood volume flow, which has been criticized by Sheard.[2] In view of these criticisms, the above calculated figures should be regarded only as qualitative comparative blood flow values. Confirmatory of the relationship between blood flow and hand temperature inferred from these temperature data are results obtained using an adaptation of the plethysmographic technic of Hewlett and Van Zwaluwenburg.[3] The blood flow values found were 2.6, 2.6, 0.6, 0.5, and 1.4 cc per 100 cc of hand in one subject and 2.0, 1.1, 0.6, 0.4, and 0.8 cc per 100 cc of hand in a second subject for determinations in water at temperatures of 5, 10, 15, 20, and 25°C respectively. The above figures are the average of several determinations on each subject.

The comparative rates of blood flow inferred from the temperature data are in qualitative agreement with the results obtained with the conventional blood flow technic. Both results indicate that blood flow reaches low levels when the hand is immersed in water of 15 to 20°C and this is well known to be the case. In still colder water (10°C or below) the blood flow again increases. This fact does not seem to be generally realized, although Lewis[4] has presented evidence that vasodilation occurs in very cold water. Barcroft[1] and Freeman[5] have made studies on the blood flow in the arm and hand immersed in water of various temperatures; but neither apparently made studies at water temperatures sufficiently low to observe this effect. The lowest water temperature used by either was 13°C.

The data discussed above were obtained at a room temperature of 16°C. Other data on the temperature of the hand immersed in water were obtained at room temperatures of 24 and 32°C (Fig. 2). This figure shows that the difference between hand temperature and water temperature is generally increased as the room temperature is increased. It is, therefore, inferred that blood flow is likewise increased with increasing room temperature. This is in agreement with the findings of others, *e.g.*, Abramson *et al.*[6]

Summary. Skin temperature measurements made on the hand immersed in water of various temperatures show that the difference between skin and water temperatures is minimal when the hand is immersed in moderately cold water (15 to 20°C). With the higher (25°C) or lower (5 and 10°C) water temperatures studied, this difference is increased. The effect of increasing the temperature of the ambient air is generally to increase the difference between skin and water temperature; however, in very cold water, ambient air temperature seems to have less influence on this difference.

These results are discussed in terms of blood volume flow and the inference is made that blood flow through the hand passes through a minimum as the hand temperature is progressively lowered. This conclusion was verified using the plethysmographic technic of blood flow determination.

[1] Barcroft, J., *J. Physiol.*, 1943, **102**, 5.

[2] Sheard, Charles, *J. Clin. Invest.*, 1926, **3**, 327.

[3] Hewlett, A. W., and Van Zwaluwenburg, J. G., *Heart*, 1909, **1**, 87.

[4] Lewis, Thomas, *Heart*, 1929-1931, **15**, 177.

[5] Freeman, N. E., *Am. J. Physiol.*, 1935, **113**, 384.

[6] Abramson, D. I., and others, *Am. Heart J.*, 1939, **17**, 206.