Relation of Basal Metabolic Rate to Vasodilatation and Vasoconstriction of the Extremities of Normal Subjects as Measured by Skin Temperatures

By Grace M. Roth, Ph.D., and Charles Sheard, Ph.D.

Various indirect methods of measuring blood flow in the peripheral blood vessels of man are available. Irrespective of the method used for measuring blood flow, certain fundamental factors concerned with the status of the subject or patient influence the measurement of blood flow. These factors are environmental temperature, position of the extremities and food. The present investigation indicates that a consideration of the basal metabolic rate or basal heat production is another important factor.

The measurement of blood flow in the peripheral blood vessels of the extremities of man is necessarily indirect. The plethysmograph, which measures the changes in volume of the extremity, the calorimeter, which measures the amount of heat given off from the extremity to a known amount of water, and thermocouples and radiometers, which measure changes in skin temperatures of the extremities, have become available for these measurements. We believe that certain fundamental factors influence the blood flow in the peripheral blood vessels of the extremities of man and that further consideration of these factors is necessary when studies of blood flow are made.

We have shown previously by use of thermocouples that the control of environmental temperature and the intake of food are important factors in the control of the heat-regulating mechanism and particularly in the production of vasodilatation. Also, the position of the extremity may play a role. We also believe that the basal heat production must play an important role in the consideration of vasoconstriction and vasodilatation.

In 1933, Maddock and Coller have shown a simple linear relationship in the same individual between the skin temperatures of the great toe and the basal heat production per unit of surface area. In 1940, Sheard and Williams, studying a small group of normal individuals under specified standard environmental conditions, found a similar linear relationship but with some indication of a twofold division or dual character. Since, in both instances, the number of subjects observed was not large, we have extended this investigation to include a much greater number of subjects. Furthermore, the question has arisen as to whether there is any relation between the basal metabolic rate and the amount of cooling of the extremities during vasoconstriction or the amount of warming of the extremities during vasodilatation.

Procedure

Basal metabolic rates and skin temperatures of the fingers and toes were determined on 189 normal subjects. The group consisted of 139 men and 20 women between the ages of 20 and 50 years. In addition, studies were made on 2 boys of 12 years of age, a man of 51 years and another of 70 years. Before the tests the subjects fasted for fifteen hours and during the tests they wore lightweight, short pajamas and lay supine on a comfortable bed in a constant temperature room kept at 25.5 C. (78 F.) with a relative humidity of 40 per cent.

The basal metabolic rates were determined by a modification of the Tissot gasometric method, and the expired air was analyzed in a Haldane gas analyzer. The tests were made just before or during the control period when the measurements of the skin temperatures were being made.

In 27 of these normal subjects, subsequent to the control studies made in a constant environmental temperature of 25.5 C. (78 F.), vasoconstriction was determined by measurement of the cutaneous temperatures of the extremities when the subject was moved to a cooler environment of 20 to 21 C. (68.0 to 69.8 F.) and a relative humidity of 40 per cent. After remaining in this environment for an hour, the subject was moved to a warmer environment of 30 to 32 C. (86 to 89.6 F.) and remained there for an-
other hour, and the degree of vasodilatation was determined from the changes in the cutaneous temperature of the extremities. In 13 additional subjects vasodilatation was determined by moving the subject from the constant temperature room of 25.5 C. (78 F.) to the warmer environment of 30 to 32 C. (86 to 89.6 F.) for an hour. Since it has been shown by several investigators that vasodilatation is produced by the ingestion of a substantial meal, we also measured skin temperatures of the extremities and metabolic rates before and after the ingestion of food in 10 of these normal subjects.

The temperatures of the plantar surface of the first and third toes of both feet and the volar side of the distal phalanges of the first and third fingers of both hands were determined by means of copper-constantin thermocouples. The observations were made at intervals of ten minutes for three to four hours. The presence or absence of sweating of the extremities was noted in all cases.

**RESULTS**

The relationship between the average skin temperatures of the toes and the calories per square meter of surface area per hour for 189 normal subjects whose ages ranged from 12 to 70 years is shown in figure 1. There is a definite indication of a dual linear relationship between the metabolic rates and the skin temperatures, since the plotted points fall into two divisions indicated by the heavy lines with a minimal density of points in the region of the broken line. Since the relationship between the values of the abscissas and ordinates is linear, it may be expressed as \( x = ay + b. \) The equations for the three lines in figure 1 are: (1) \( x_1 = 1.18 \, y_1 + 1; \) (2) \( x_2 = 1.18 \, y_2 + 4; \) and (3) \( x_3 = 1.18 \, y_3 + 6. \) The lowest basal rate of any subject was 26.8 calories per square meter per hour in a man aged 21 years, and the highest rate of 45.8 calories per square meter per hour was found in a man aged 25 years. The rate for the 2 boys was 46.2 and 42.2 calories per square meter per hour respectively.
and that for the 70 year old man was 30.4 calories per square meter per hour. The lowest skin temperature of the toes was 21.6 C. (70.7 F.) in the man aged 21 years, who also had cold, clammy feet, and the highest temperature was 34 C. (93.2 F.) in a man of 39 years with hot, dry feet.

The mean basal production of heat and the mean skin temperature of the toes of the subjects are grouped in Table 1 according to the ages of the individuals as well as according to sex. There was a significant difference in the mean calories per square meter per hour between the ages of 20 to 29 years and 30 to 39 years and again between the ages of 30 to 39 years and 40 to 49 years. The slight decrease in initial basal metabolic rate. A greater period of time was required to obtain a maximal vasodilatation in the toes of the subject with the lower basal metabolic rate. The mean for the group of 10 subjects before the meal was 36.9 calories per square meter per hour and 27.3 C. (81.2 F.) for the temperatures of the toes, whereas the mean after the meal was 44.7 calories per square meter per hour and 32.3 C. (90.2 F.) for the skin temperatures of the toes. Individually the basal metabolic rates of these subjects ranged from 30.6 to 42.4 calories per square meter per hour prior to the ingestion of the meal and from 33.8 to 50.1 calories per square meter per hour after the meal, and the skin temperatures of the toes

<table>
<thead>
<tr>
<th>Age group, yr.</th>
<th>Cases</th>
<th>Mean B.M.R.</th>
<th>Mean skin temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Per cent</td>
<td>Calories per square</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>meter per hour</td>
</tr>
<tr>
<td>20-29</td>
<td>133</td>
<td>-9.9</td>
<td>36.9 ± 0.3*</td>
</tr>
<tr>
<td>30-39</td>
<td>44</td>
<td>-8.3</td>
<td>35.3 ± 0.4</td>
</tr>
<tr>
<td>40-49</td>
<td>8</td>
<td>-1.0</td>
<td>37.9 ± 1.4</td>
</tr>
<tr>
<td>All Groups</td>
<td>185</td>
<td>-9.1</td>
<td>36.6 ± 0.3</td>
</tr>
<tr>
<td>Men</td>
<td>151</td>
<td>-9.8</td>
<td>37.0 ± 0.3†</td>
</tr>
<tr>
<td>Women</td>
<td>26</td>
<td>-7.0</td>
<td>33.5 ± 0.6</td>
</tr>
</tbody>
</table>

* t <0.001; † t <0.001; ‡ t = 0.001.

the calories per square meter per hour in the 30 to 39 year group when compared with the other two age groups was not accompanied in our subjects by a decrease in the mean skin temperature of the toes. On the contrary there was a small increase in the mean skin temperature of the toes over the 20 to 29 year group. The smaller mean number of calories per square meter per hour of women in contrast to men found its counterpart in a slight but significant lower mean skin temperature of the toes.

The curves of figure 2 show the increase of the skin temperatures of the toes as well as of the metabolic rates in 2 individuals after the ingestion of a substantial meal; one of these individuals had a high (42.4 calories per square meter per hour) and the other a low (33.8 calories per square meter per hour) ranged from 22.5 to 31.6 C. (72.5 to 88.8 F.) before taking food to 30.2 to 34.3. C. (86.4 to 93.8 F.) after the meal.

The data in Table 2, covering 40 normal subjects grouped according to basal heat production, show the average periods of time necessary to produce a state of vasodilatation indicated by a rise of the skin temperature of the toes to 33 C. (91.4 F.) in the warm room. As the basal heat production increases, the period of time necessary to produce vasodilatation of the toes decreases. The data of Table 3, obtained on 27 normal subjects grouped according to the basal rate of heat production, show the periods of time required to produce vasoconstriction, as indicated by a skin temperature of the toes of 20 C. (68 F.), in an environmental temperature of 20 C. (68 F.).
Table 2.—Time Necessary to Produce Vasodilation in a Warm Room as Evidenced by an Increase of the Skin Temperature of the Toes to 33 C. (91.4 F.) of Forty Normal Subjects Grouped According to the Basal Metabolic Rate

<table>
<thead>
<tr>
<th>Subjects</th>
<th>B. M. R., calories per square meter per hour</th>
<th>Time, min</th>
<th>Skin temperature of toes, degrees C.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>31-34.9</td>
<td>180</td>
<td>33</td>
</tr>
<tr>
<td>23</td>
<td>35-39.9</td>
<td>93</td>
<td>33</td>
</tr>
<tr>
<td>10</td>
<td>40-44.9</td>
<td>60</td>
<td>33</td>
</tr>
<tr>
<td>3</td>
<td>45-49.9</td>
<td>25</td>
<td>33</td>
</tr>
</tbody>
</table>

Table 3.—Time Necessary to Produce Vasocostriction in a Cool Room at 20 C. (68 F.) as Evidenced by a Decrease of the Skin Temperature of the Toes to 20 C. (68 F.) of Twenty-seven Normal Subjects Grouped According to the Basal Metabolic Rate

<table>
<thead>
<tr>
<th>Subjects</th>
<th>B. M. R., calories per square meter per hour</th>
<th>Time, min</th>
<th>Skin temperature of toes, degrees C.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>30-34.9</td>
<td>38</td>
<td>20</td>
</tr>
<tr>
<td>17</td>
<td>35-39.9</td>
<td>73</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>40-44.9</td>
<td>108</td>
<td>20</td>
</tr>
</tbody>
</table>

*Calories per square meter per hour

**Fig. 2.—**The increase of the skin temperatures of the toes as well as the metabolic rate after the ingestion of a substantial meal in two normal individuals. A, The subject with high basal heat production. B, A subject with a low basal heat production. The curves show a delay in the rise in the skin temperatures of the toes in the subject with the lower basal heat production.

Under these conditions, the greater the initial production of heat the longer it takes to produce vasoconstriction in the toes. In 8 other subjects, with basal heat productions ranging from 40.8 to 50.1 calories per square meter per hour subjected to the same cool environmental temperature of 20 C. (68 F.), it was found that, after ninety to one hundred and twenty minutes of exposure, the decrease of the skin temperature of the toes ranged from 3.9 to 9.4 C. (7 to 16.9 F.) above the environmental temperature. This decrease indicated that some degree of vasoconstriction had occurred, but not as much as in the other subjects with lower basal heat production.

The curves of figure 3 show the effects of moist extremities on the skin temperatures of the toes of 2 normal individuals, one with a rather low (−14 per cent) basal metabolic rate and the other with a higher rate (−3 per cent). The data in both instances show that, with damp feet, the temperatures of the toe remained constant but 1 to 1.5 C. (1.8 to 2.7 F.) below the room temperature.
When the subjects were placed in an environmental temperature of 28 C. (82.4 F.) with relative humidity of 40 per cent, the extremities of the individual with higher basal metabolism (fig. 3, A) became normally dry, vasodilatation of the extremities occurred as is evidenced by the increase in temperature of the toe and, in the course of an hour, a condition of maximal vasodilatation was exhibited. In the individual with the lower metabolic rate (fig. 3, B), the feet were still damp in an atmosphere of 28 C. (82.4 F.) and vasoconstriction of the extremities, particularly in the feet, was present. However, a change of 1.5 C. of the environmental temperature (from 28 to 29.5 C. or 82.4 to 85.1 F.), produced normal dryness of the extremities, followed by normal vasodilatation as is evidenced by the skin temperatures of the fingers and of the toes.

**COMMENT**

Production of heat in the body must equal loss of heat from the body if the internal temperature is to be maintained at a constant value. The metabolic rate is a measure of the production of heat. The dissipation of heat is carried on by the processes of radiation, evaporation, conduction and convection. If the losses due to convection, conduction and evaporation are controlled and kept constant under specified environmental conditions, then the additional losses of heat may be measured by radiometers or thermocouples, since both instruments may be used to measure the temperatures of various areas of the body. As has been pointed out in other contribu-

![Graph](image)

**Fig. 3.—The effect of moisture on the skin temperatures of the toes of two normal subjects. A, Subject had a low basal metabolic rate. B, A higher basal metabolic rate. The curves show a delay in vasodilatation of the feet in the subject with the more moist extremities and the lower metabolic rate.**

of 28 C. (82.4 F.) the skin temperatures of the toes are the most sensitive or delicate indicators of the vasomotor regulation of the dissipation of heat under any environmental conditions in which vasomotor regulation is the chief and, ideally, the only source of regulation. If, however, areas of the body, and particularly the lower extremities, are moist, then regulation of loss of heat is accomplished in part by evaporative losses. Hence, in individuals with the same basal metabolic rates it would be expected that the skin temperatures of the toes would be lower among those with moist extremities. The data plotted in the diagram (fig. 1) give
the experimentally obtained relationship between the skin temperatures of the toes and the calories per square meter per hour, and show a definite tendency to be grouped into two divisions. This dual grouping is dependent primarily on the degree of dryness or dampness of the surface of the body.

When metabolic rates are changed by the ingestion of food, and the subjects are kept under constant standard environmental conditions, the rates of increase of the temperatures of the toes are fairly closely proportional to the basal heat production. The foregoing statement also holds when individuals in the basal state are moved from a standard environment of 25.5 C. (78 F.) to a warm room (31 C., or 87.8 F.).

Stewart and Evans\(^{2}\) also demonstrated in normal subjects that under basal conditions at an environmental temperature of 25 C. (77 F.), peripheral blood flow is usually less with a lower basal metabolic rate and greater with a higher basal metabolic rate.

Kirklin, Plummer and Sheard\(^{1}\) reported measurements of skin temperature in cases of exophthalmic goiter before and after administration of strong solution of iodine (Lugol’s solution) and before and after partial thyroidectomy. They found that with a reduction of basal metabolic rate following either the administration of Lugol’s solution or partial thyroidectomy there is a reduction in the skin temperature of the toes.

Also, Roth, Williams and Sheard\(^{1}\) found that, with production of thiamine deficiency, measurements of skin temperature at various times during the period of restriction showed a more or less close correlation with the basal metabolic rates, rather than with the severity of the clinical symptoms.

**Summary**

The experimental data given in this paper, as well as the evidence furnished by other approaches to the problem, show the importance of a consideration of basal heat production in studies concerning vasodilatation or vasoconstriction as measured by skin temperatures of the extremities in normal subjects or patients with pathologic conditions.

**REFERENCES**

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