Vasomotor Reactions to Heat among Patients with Arterial Disease

By Travis Winsor, M.D.

Plethysmographic studies of the vasomotor reactions of the digits accompanying body heating were of value in the early detection of peripheral arterial disease. In normal individuals, labile vasomotor activity was shown by great changes in digital volume (a large pulse, alpha and beta waves). These changes were diminished or absent in patients with peripheral arterial disease.

It has long been recognized that the response to body heating, as demonstrated through measurements of the resulting changes in the skin temperature of the extremities, permits a gross but useful estimate of the vasomotor reactions in patients with arterial disease. In the meantime, the plethysmographic method has been considerably improved through the introduction of a portable appliance as well as of a set of terms describing the characteristic wave forms in the plethysmogram. Through application of this method it has now become possible to ascertain the finer details of the vasomotor responses to body heating as they become apparent in the digits of normal individuals as well as of patients with arterial disease. Thus, characteristic patterns can be distinguished, which may prove of considerable aid in the diagnosis of peripheral vascular disease.

Vasomotor reactions to body heating were studied in 20 normal individuals and 20 patients with arterial disease. The age of the normal individuals varied between 19 and 28 years, with an average of 21 years; 16 were men, four were women. Of the patients with arterial disease, 14 had arteriosclerosis obliterans, while 6 suffered from thromboangiitis obliterans; in ten instances, arterial disease had progressed to ulceration of heel, foot or digits.

Experiments were conducted in a room with a temperature of 25 C. ± 1.5 degrees, the air velocity amounting ordinarily to less than 8 feet per minute, but at no time exceeding 12 feet per minute. In normal individuals, control tests were first carried out, following a rest period of sixty minutes' duration, with the subject lying on a horizontal bed, dressed in a hospital gown and covered with one light woolen blanket.

Body heating was accomplished by covering the individual with two woolen blankets, as well as two electric pads measuring 34 x 64 cm. One pad was placed horizontally across shoulders, arms and chest, and the other longitudinally upon the legs. The pads were applied warm and were inserted between the blankets, which were tucked snugly about the neck, while fingers and toes remained exposed.

The Cambridge pneumo-plethysmograph was employed and the plethysmogram was standardized so that volume changes were obtained in cubic millimeters per 5 cc. of tissue per second. The amplitude of pulsations was recorded in cubic millimeters per 5 cc. of tissue.

A digital cup was fastened to the right or left second toe with a non-constricting sealing material. The blood flow of the digits was determined through venous occlusion. The collecting cuff was placed at the wrist or ankle and in selected cases at finger or toe. Venous occlusion was ordinarily accomplished by quickly inflating the collecting cuff to a pressure of 60 mm. Hg. Lower pressures were employed in selected patients with arterial disease. Flow rates obtained with the collecting cuff at the
wrist or ankle are referred to as relative flow rates.

Waves of the Normal Plethysmogram

Ordinarily, at least five different types of waves can be recognized in the plethysmogram\textsuperscript{10,14}: pulse, respiration, alpha, beta and gamma waves (fig. 1).

The pulse wave represents changes in the digital volume, which are primarily influenced by cardiac output, caliber of arteries and arterioles, as well as tissue distensibility. Contour, frequency and amplitude of the pulse wave are often modified through arterial disease.\textsuperscript{15–19} The contour of the pulse wave in the plethysmogram is not unlike that of the arterial pulse wave. The dicrotic notch can ordinarily be observed in the plethysmogram of normal individuals resting in a comfortable environment, and it becomes more prominent following body heating. In the plethysmogram of patients with advanced arterial obstruction, on the other hand, it is, as a rule, not possible to detect a dicrotic notch, even after body heating. The frequency of the wave is determined by the pulse rate. The amplitude of the pulse wave in the plethysmogram is constant only in the presence of extreme vasodilatation or vasoconstriction, but varies when the sympathetic tone is labile, as especially in normal individuals at ease in a comfortable environment. The amplitude is reduced under the influence of cold or pain, and by many emotional states, especially startle, fear, fright, anxiety, and probably embarrassment, as well as by certain mental processes, as for example simple multiplication. It is, on the other hand, increased through relaxation, contentment and sleep, and also by medication with nitroglycerin and prostigmine, as well as through general anesthesia and spinal and peripheral nerve block.\textsuperscript{20}

The respiration wave is an expression of inconstant variations in the digital volume, dependent upon pulmonary activity.\textsuperscript{21–22} Inspiration ordinarily produces decrease of digital volume; expiration results in rise in systemic blood pressure and concomitant increase of digital volume.\textsuperscript{23–28} Contour, frequency and amplitude of respiration waves depend not only on type and frequency of respiration but also on numerous other factors; the waves may, for instance, be small or entirely absent in patients with arterial disease, and become occasionally more conspicuous under the influence of body heating. Respiration waves are generally more pronounced in the fingers than in the toes, presumably because of higher vasomotor tone in the lower extremities.

The alpha, beta and gamma waves result in all probability from changes in vasomotor tone, and are of lower frequency than the other waves. These waves are often independent of variations in the blood pressure\textsuperscript{27} and under carefully controlled conditions show a characteristic rhythmic pattern. Contour and amplitude of alpha, beta and gamma waves are subject to numerous influences: they are enlarged through contentment, sleep,\textsuperscript{29} and mild body heating, but are reduced through anxiety or in patients suffering from certain types of arterial or tissue diseases. Alpha waves in the plethysmogram may or may not be accompanied by beta and gamma waves.\textsuperscript{30} In addition to changes in vasomotor tone, gamma waves are dependent on shifts in tissue fluids\textsuperscript{29, 30} and also on variations of the temperature in the immediate environment of the digit.

Influence of Body Heating on the Plethysmogram of Healthy and Diseased Individuals

The results of the previously outlined experiments lead to the conclusion that normal individuals, patients with moderate arterial disease without ulceration, and patients with advanced arterial disease with ulceration of the extremities show distinct differences in their respective vasomotor reactions toward body heating.

In the plethysmogram of a normal individual, application of damp towels to legs and trunk for a period of five minutes resulted in low pulse and alpha waves, while no respiration and beta waves could be observed (fig. 2, A). Clinically, the patient presented cool, white extremities with constricted veins, indicating a high grade of vasoconstriction as well as a markedly decreased rate of blood flow. When, after removal of the damp towels, the body was covered with a sheet, the pulse waves increased in amplitude
Fig. 1.—Five different types of waves can be recognized in the plethysmogram: pulse, respiration, alpha, beta, and gamma waves, with a frequency of 60, 16, 5.5, 1, and 0.1 cycles per minute, respectively.
and beta waves became apparent (fig. 2, B). A tracing made ten minutes after the patient had been covered with a light woolen blanket and two electric pads were applied revealed pulse waves of variable amplitude and moderate size, as well as more prominent alpha and beta waves (fig. 2, C). Clinically, it was observed that the patient’s skin was warmer and had a more pinkish appearance, due to increased blood flow and probably also to early release of vasomotor tone. A second blanket was added at this time, and after twenty-three minutes of body heating it was observed that the pulse waves were of variable amplitude, becoming larger with increasing digital volume, while the beta waves were regular and of high amplitude and frequency (fig. 2, D). Another plethysmogram made after heat had been applied for thirty minutes showed further increase in the amplitude of the pulse waves, particularly at the spicules of the beta waves. The alpha waves were less prominent than in earlier tracings, while the beta waves showed lower frequency combined with high amplitude (fig. 2, E). After forty-five minutes of heat the amplitudes of the pulse waves were large and constant, but alpha and beta waves had become small (fig. 2, F). Clinically, the digits were hot, pink and damp, and with dilated veins, indicating a high degree of vasodilatation and little fluctuation in the vasomotor tone.

Whenever the wave pattern in serial plethysmographic tracings shows these typical changes it may be concluded that the arterial system is patent, the digital tissues possess normal distensibility, and the sympathetic nervous system is intact.

The relative toe flow, which after application of damp towels amounted to 4.0 cu. mm. per 5 cc. per second, rose progressively to reach a value of 33.0 cu. mm. per 5 cc. per second after forty-five minutes of body heating. This increase of blood flow to the toe is not only due to a decrease in peripheral resistance but probably also to greater cardiac output.

The mean, maximum, and minimum values for pulse, respiration, alpha and beta waves as well as the rates of blood flow to the toe obtained in tracings of twenty normal subjects at room temperature and during ten to forty minutes of body heating are presented in table 1.

The changes in the plethysmogram of patients with moderate arterial disease without ulceration of the extremities, brought about through body heating, show characteristic differences from the response of normal individuals. This fact becomes clearly apparent in the tracings of a 42 year old woman who was hospitalized because of backache, menorrhagia and intermittent claudication of four years’ duration. After walking one quarter of a block, bilateral thigh and calf pains developed and the patient exhibited the “aortic waddle.” An abdominal systolic murmur was recorded. Oscillographic readings above the knees were 0.5 unit, above the elbows 6.0 units. Blood pressure above the knees amounted to 90 mm. Hg, above the elbow to 140 mm. Hg. The diagnosis was arteriosclerosis obliterans of the abdominal aorta.

With the patient resting in a comfortable environment the pulse waves had an amplitude of 0.0 cu. mm., respiration waves were absent, alpha waves insignificant, while beta waves with an amplitude of 8.0 cu. mm. occurred at a frequency of one cycle per minute. The relative blood flow to the toe was 1.5 cu. mm. per 5 cc. per second, (fig. 3, A). Following application of heat to the body for thirty-five minutes, the pulse wave increased to 0.5 cu. mm., respiration waves occasionally became visible, and alpha waves showed amplitudes of 4.0 cu. mm. with a frequency of 6 per minute, while the amplitude of beta waves measured approximately 15.0 cu. mm. with a frequency of 0.9 cycle per minute. Relative blood flow to the toe had increased to 6.8 cu. mm. per 5 cc. per second (fig. 3, B).

The findings in this case are typical of the plethysmogram of patients with moderate arterial disease in which the contour of the pulse wave is often rounded, especially following application of heat, and the dicrotic notch remains indistinct. While thus a moderate lack of vasomotor response becomes apparent, a sufficient degree of vasomotor activity is still encountered in patients of this type to suggest that benefit may be expected from medical treatment or sympathectomy. Subcutaneous injection of prostigmine, 1:1000, was carried out in 5 of a
Fig. 2.—Effect of body cooling and body heating on the wave pattern of the plethysmogram in a normal 25 year old man. Body cooling (A) resulted in lowered pulse and alpha waves, indicating marked vasoconstriction. Intense body heating (E) (next page) resulted in pulse waves of high amplitude accompanied by small alpha and beta waves, indicating a high degree of vasodilatation. Intermediate degrees of body heating (B, C, D, E) resulted in pulse waves of variable amplitudes and large alpha and beta waves.
### Table 1.—Mean, maximum and minimum values for pulse, respiration, alpha and beta waves as well as rates of blood flow to the toe obtained in twenty normal subjects, at room temperature and during body heating, for varying periods of time

<table>
<thead>
<tr>
<th></th>
<th>Pulse Waves (Cu.mm.)</th>
<th>Respiration Waves† (Cu.mm.)</th>
<th>Alpha Waves</th>
<th>Beta Waves</th>
<th>Blood Flow (Cu.mm. per 5 cc. per sec.)</th>
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<tr>
<td></td>
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<td>Cycles per min.</td>
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<td>Mean</td>
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<td>1.1</td>
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<td>15.6</td>
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<td>Min.</td>
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<td>1.1</td>
<td>2.2</td>
<td>8.8</td>
<td>12.6</td>
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* Duration of body heating.
† Respiration waves appeared in only 8 subjects.
Fig. 3.—Effect of body heating on the wave pattern of the plethysmogram in a patient with moderate arterial disease without ulceration of the extremities. Body heating (B) resulted in the appearance of pulse, alpha and beta waves, suggesting a fair degree of vasomotor activity. The relative blood flow to the toe increased moderately to a value of 6.8 cu. mm. per 5 cc. per second, as compared with a normal of 30.0 cu. mm. This patient derived subjective and objective benefit from sympathectomy.
Table 2.—Mean, maximum and minimum values for pulse, respiration, alpha and beta waves as well as rates of blood flow to the toe obtained in ten patients with moderate arterial disease without ulceration of the extremities, at room temperature and during body heating for varying periods of time.

<table>
<thead>
<tr>
<th>Pulse Waves (Cu.mm.)</th>
<th>Respiration Waves† (Cu.mm.)</th>
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<th>Beta Waves</th>
<th>Blood Flow (Cu.mm. per 3 cc. per sec.)</th>
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<td>Ankle Cuff 0.6 4.2 3.5 3.5 1.0</td>
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* Duration of body heating.
† Respiration waves appeared in only 3 patients.
series of 10 patients with moderate arterial disease, and produced amplitudes of the pulse waves three times as large as those observed prior to medication, with the patient resting in a comfortable environment. Lumbar sympathetic block in 10 patients, spinal anesthesia in 4 patients, as well as lumbar sympathectomy in 5 patients resulted in an increase of the amplitudes of the pulse waves to four times the value of earlier readings with the patient in a comfortable environment, and also caused almost complete disappearance of alpha and beta waves. At the same time, the rate of blood flow to the toe increased three to eight times.

In the case mentioned above, right sympathectomy was advised. At time of operation the aorta was found to be small and firm, and an aortic thrill was detected. Seven days postoperatively the plethysmogram showed pulse waves with amplitudes of 0.6 cu. mm., alpha and beta waves were insignificantly small, and blood flow to the toe amounted to 5.7 cu. mm. per 5 cc. per second (fig. 3, C). Skin temperatures had increased 9 degrees C., and systolic blood pressure of the ankles was 10.0 mm. Hg. higher than preoperatively. Following uneventful recovery the patient was able to walk eight blocks without pain, and unquestionably sympathectomy proved to be of subjective as well as objective benefit.

The mean, maximum, and minimum values for pulse, respiration, alpha and beta waves as well as the rates of blood flow to the toe, obtained in tracings of 10 patients with moderate arterial disease without ulceration of the extremities observed at room temperature and during ten to forty minutes of body heating, are presented in table 2.

In the plethysmogram of individuals with advanced arterial disease with ulceration of the extremities, only small changes can be observed following application of heat to the body, as evident in the tracings of a 73 year old woman. A small ulcer appeared on the dorsum of the left fourth toe and she complained of pain in both legs on walking 50 steps. Systolic blood pressure of feet, ankles, calves and thighs was distinctly lower than in hand, wrist, antecubital, and brachium. The diagnosis was arteriosclerosis obliterans of the abdominal aorta and popliteal artery.

When the patient was resting in a comfortable environment, no pulse, respiration, alpha or beta waves appeared in the plethysmogram (fig. 4, A). After fifteen minutes of body heating, beta waves not exceeding 5 cu. mm. could be observed (fig. 4, B), but they were much less prominent, attaining not even to 2.0 cu. mm., when heat was applied for a period of thirty minutes (fig. 4, C). At the same time the relative rate of blood flow to the toe, which had increased from 0.1 cu. mm. per 5 cc. per second at room temperature to 1.1 cu. mm. per 5 cc. per second following fifteen minutes of body heating, again declined after thirty minutes to 0.1 cu. mm. per 5 cc. per second. This effect is probably due to vasodilatation of normal vessels elsewhere in the body, causing the blood to be shunted away from the diseased extremity. 

Observations in a group of 10 patients with advanced arterial disease with ulceration of the extremities showed that evidence of vasomotor activity following body heating was almost completely lacking in the plethysmogram. This finding, together with a minimal increase in the relative blood flow to the toe, is indicative of severe organic arterial disease, while hardly any vasospasms is present, and only little collateral circulation available. It is therefore not surprising to find that 5 patients treated with subcutaneous injections of proprigmine, 1:1000, showed no peripheral vascular response. Intravenous injection of tetraethylammonium chloride, 500 mg., also failed to produce any changes in the plethysmographic pattern. Lumbar sympathectomy performed in 5 patients was not followed by any definite changes in the plethysmogram or by increased blood flow to the toe. This negligible benefit of surgery is clearly demonstrated in the case mentioned above (fig. 4, D). No significant postoperative improvement was observed in any of these patients.

The mean, maximum, and minimum values for pulse, respiration, alpha and beta waves as well as the rates of blood flow to the toe, obtained in tracings of 10 patients with moder-
Fig. 4.—Effect of body heating on the wave pattern of the plethysmogram in a patient with advanced arterial disease, with ulceration of the extremities. Body heating (B) resulted in the appearance of low beta waves. The relative toe flow increased slightly with mild body heating, but decreased with prolonged application of heat (C). This patient was not materially benefited by lumbar sympathectomy (D).
Table 3.—Mean, maximum and minimum values for pulse, respiration, alpha and beta waves as well as rates of blood flow to the toe obtained in ten patients with advanced arterial disease with ulceration of the extremities at room temperature and during body heating for varying periods of time.

<table>
<thead>
<tr>
<th></th>
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<th>Respiration Waves (Cu.mm.)</th>
<th>Alpha Waves†</th>
<th>Beta Waves</th>
<th>Blood Flow (Cu.mm. per 5 per sec.)</th>
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* Duration of body heating.
† Appeared in only one patient.
ate arterial disease with ulceration of the extremities observed at room temperature and during ten to forty minutes of body heating, are presented in table 3.

A comparison of the submitted data shows that the vasomotor changes following body heating produce characteristic differences in the plethysmographic wave pattern. Plethysmographic tracings are, therefore, of great aid in evaluating the degree of arterial disease present, as well as in deciding on a course of therapy.

**Summary**

The pneumo-plethysmograph was employed to study the vasomotor response to body heating in three groups of subjects: normal individuals, patients with moderate arterial disease without ulceration of the extremities, and patients with advanced arterial disease with ulceration of the extremities. The changes in the plethysmogram of normal individuals, occurring after body heating for varying periods of time, indicate the presence of marked vasomotor activity. Tracings of individuals with moderate arterial disease show, under the influence of body heating, wave forms of lower amplitudes, while in the presence of advanced arterial disease only marginal changes occur in the plethysmographic wave pattern. From these findings it can be deduced that in moderate arterial disease a diminished degree of vasomotor activity remains, yet sufficiently great to make medical treatment or sympathectomy advisable. In advanced arterial disease, on the other hand, vasomotor activity is almost completely absent, and no substantial benefit can be expected from either form of treatment.

Plethysmographic tracings can be of great aid in planning the most promising course of therapy in peripheral vascular disease.

**Acknowledgments**

Gratitude is expressed to Dr. B. O. Raulston for the encouragement and cooperation extended during the course of this research. The valuable technical assistance of Grayce S. Fleming is sincerely acknowledged.

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