Effect of Changes in Posture on Peripheral Circulation, with Special Reference to Skin Temperature Readings and the Plethysmogram

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Effects of changes in posture upon plethysmogram and skin temperature are investigated. Since posture, by altering venous return, affects pulse volume and response of digital volume and skin temperature to procedures releasing sympathetic tone, these should not be interpreted solely in terms of arterial blood flow. In the normal elevated limb, e.g., the skin temperature response to body heating simulates organic arterial disease. The clinical significance of these findings is discussed with particular reference to interpretation of skin temperature readings, the diagnosis of thromboangiitis obliterans, indications for sympathectomy in poliomyelitis, the management of the edematous limb and other conditions.

Although there is an extensive literature on the response of the circulation in general to changes in posture, very little has been reported so far as to the changes caused by posture on the peripheral circulation in a strict sense. In man, assuming the erect position produces a rise in the general blood pressure (particularly in the diastolic blood pressure), increases the heart rate, and produces a decrease in the plasma volume by about 15 per cent.\(^1\)\(^-\)\(^4\) With regard to the cardiac output, numerous authors\(^5\)\(^-\)\(^7\) have reported that assuming the erect posture will decrease the minute volume, although this observation has been questioned by Grofman\(^8\) and by Goldbloom and associates.\(^9\) It is well known that prolonged quiet standing puts a severe strain upon the circulation, as demonstrated by the frequency of fainting. While some animals die from cerebral anemia if kept upright,\(^10\) others, especially man, may alter their posture from the horizontal to the erect without impairment of the circulation. This, almost of itself, suggests that there must exist certain mechanisms of adaptation, since the blood would otherwise tend to accumulate in the most dependent parts. Most persons have experienced some degree of swelling of the legs on long, quiet standing; indeed, this has been demonstrated scientifically by numerous workers.\(^2\)\(^-\)\(^11\)\(^-\)\(^12\) Atzler and Herbst\(^13\) calculated that about 500 cc. of extra blood may accumulate in the legs during quiet standing for one hour and Grill\(^14\) found the increase to be 4 per cent of the leg volume.

Obviously, the marked changes in hemodynamics, particularly the increase in hydrostatic pressure, which result from the assumption of the upright posture, produce profound changes in the peripheral circulation and set in train definite mechanisms of adaptation on the part of the peripheral vessels. Bock, Dill, and Edwards\(^15\) demonstrated that the acceleration of the heart rate normally observed following the injection of histamine into an ankle vein takes twice as long if the subject is erect than if recumbent. That this is not due solely to an increase in the cross-section area of the vascular tree caused by a distention of the vessels by the hydrostatic pressure is suggested by the reduction in the oxygen saturation in the blood of the femoral vein during maintenance of the erect posture, as reported by Florken, Edwards, and Dill.\(^16\) This suggests that there is a reduction in the blood flow through the lower extremities in the erect posture, and indeed this has been demonstrated plethysmographically by Proger and Dexter.\(^17\) Doupe and his collaborators\(^18\) pointed out that the increase in venous pressure in the dependent posture results in an increase of venous tone (venous stretch reflex) which is abolished on elevation due to the drop in venous pressure, causing relaxation of the peripheral blood vessels. It is the venous stretch reflex which prevents the pooling of blood in the upright posture. We ourselves\(^19\)\(^-\)\(^20\) have already demonstrated that

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changes in posture markedly influence the peripheral blood flow, as judged by the plethysmographic record, although at the time we did not go into any detail.

**Methods and Material**

The methods used in this study followed closely those previously described and the reader is referred to earlier articles. Continuous records of the peripheral blood flow were obtained by using our digital plethysmograph. In this the digit is enclosed within a glass cup which is connected to a pipet, graduated in 0.01-cc. units, containing a column of alcohol. When the plethysmograph is sealed with petrolatum and the tap closed, the volume changes in the digit are transmitted to the alcohol column, the movements of which are enlarged and projected onto the paper of a recording camera. Since the publication of a preceding article, the method has been perfected in such a way that now two pipets are mounted next to each other and thus it is possible to record simultaneously the changes in peripheral blood flow of two digits, either of the same or of different extremities. A portable model has been constructed as well. This plethysmographic method is capable of exact and undistorted measurement of the changes in skin volume, and differences of 0.001 cc. are recorded easily. In many films the respiratory changes or the skin temperatures (determined by means of thermocouples) were recorded simultaneously with the plethysmogram. The rate of blood flow was obtained by means of the venous congestion test previously described. In this the pressure in the obstructing cuff is recorded on the film by means of a Frank capsule. All observations were conducted in a draught-free, noiseless room. The room temperature was kept constant during the experiments. The investigations were carried out on 24 normal subjects, 6 patients with thromboangiitis obliterans, and 8 patients with venous thrombosis of the lower extremities. Although the investigations were conducted almost exclusively on the lower extremities, investigations in the upper limbs confirmed the findings and did not suggest that there was any difference between the reaction of the upper and lower limbs. The tests were performed after thirty to sixty minutes’ rest.

All our published investigations (previously reported) as well as all diagnostic tests at Groote Schuur Hospital have always been carried out with the patient resting on a special type of couch (fig. 1, A) or on a surgical bed with the subject in a similar position. Patients investigated in this position are referred to as “reclining.” In order to determine the effect of elevation on the circulation through the lower limbs, the patients were examined in a position indicated in figure 1, B, in which the back of the couch was lowered and the legs elevated to an angle of about 45 degrees above the horizontal. Limbs tested in this position are referred to as “elevated.” In addition, patients were investigated sitting on an ordinary chair or standing. The position is noted in each of the figures. A number of tests were carried out on the tilting table in the x-ray department, using the portable plethysmograph.*

*Manufactured by Hilger & Watts, London.
Reflex vasodilatation of the peripheral vessels was obtained by immersing one upper limb into water of 45 C. temperature for thirty minutes and covering the subject with blankets so as to prevent the dissipation of heat. A special thermostatically controlled tank for this procedure had been developed.28. 51 (See fig. 1, A.)

**Results**

*Effect of Posture on the Pulse Volume in the Normal Subject:* The pulse volume of the normal subject (figs. 2, B and 3, B) resting in the reclining position consists of the main systolic elevation followed by a dicrotic wave; occa-
sionally there may be a minute and insignificant accessory wave. With elevation of the limb (figs. 2, C and 3, C) the following changes are observed: the main systolic elevation becomes higher, the dicrotic wave smaller, and the ac-

crotic pulse is registered (fig. 3, C). The opposite occurs as a more dependent posture is assumed. With the subject sitting (fig. 3, A) or standing (fig. 2, A), the main systolic elevation becomes smaller, the dicrotic wave more prom-

Fig. 3.—Plethysmogram, taken at fast speed, showing the changes in the shape and height of the pulse volume in various postures. A. Sitting; B. reclining; C. elevated. Height of pulse volume in A is ± 0.01 cc.; in B ± 0.02 cc.; and in C, ± 0.04 cc.

cessory waves disappear. Consequently, the incisura or notch between the systolic and the dicrotic wave is usually less marked and often disappears completely. In some subjects, especially when the vessel is fully dilated, there may be no dicrotic wave and a typical mono-

inent, and one or two well developed accessory waves follow. The result is that three or four waves become registrable (fig. 2, A). On standing, the notch between the first (systolic) elevation and the following dicrotic wave normally reaches the base line, when, in consequence,
three to four waves often of equal size may be recorded. In such cases it may be difficult to recognize the individual pulse volume, particularly if the vessels are constricted and the pulse small.

The changes in pulse volume which take place with changes in posture can be followed easily if a continuous record is taken while the patient is being tilted from the horizontal to the erect posture (fig. 6).

Even small changes in posture have a profound effect on the shape of the pulse volume, as indicated in figure 4. In this figure the pulse and more marked and when the leg is fully elevated they are extremely prominent (fig. 2).

Changes in Digital Volume due to Changes in Posture in the Normal Subject: As has been pointed out previously, spontaneous changes in digital volume observed during rest are mainly a function of changes in pulse volume. From this it follows that during elevation, changes in digital volume are more prominent than during sitting and standing, when hardly any changes in digital volume may be recorded (fig. 2). As the limbs are elevated, the changes become more marked and in those subjects

![Plethysmogram of first toe of left foot and first toe of right foot simultaneously recorded.](image)

**Fig. 4.**—Plethysmogram of first toe of left foot and first toe of right foot simultaneously recorded. The left limb (upper tracing) was tested at an angle of 45 degrees below horizontal. The right limb (lower tracing) was kept in the horizontal posture. Note the differences in the height and shape of the pulse volume even with such slight differences in posture. A at usual and B at fast speed to show the exact shape of pulse volume.

volume of two toes is registered simultaneously. The lower record was obtained from the limb resting in the horizontal posture, while the upper record refers to the limb kept at an angle of about 45 degrees below the horizontal. The differences in the height and shape of the pulse volume are recognized easily.

In addition to these changes in the height and the shape of the individual volume pulse, posture has a marked effect upon the spontaneous changes seen normally in the height of the pulse volume which reflect the changes in central vasomotor tone. During sitting and standing the pulse volume hardly changes. However, as the legs are elevated, changes in the height of the pulse volume become more

who naturally show well developed fluctuations in vasomotor tone, spontaneous changes are very pronounced if the legs are elevated. But even small differences in posture will have an appreciable effect on the fluctuations in digital volume (fig. 5). When the tracing shown in figure 5 was taken, the patient was reclining comfortably, the one limb (upper tracing) being held in a slightly pendent posture with the knee flexed at an angle of 45 degrees against the horizontal. The other limb (lower tracing) was kept slightly elevated at an angle of about 30 degrees above the horizontal. The changes in digital volume of the slightly elevated limb are far more pronounced.

Similarly, all extrinsic and intrinsic stimuli
which normally produce a fall in digital volume, such as a deep breath, an unexpected noise, mental strain, etc., elicit a much more pronounced response in an elevated than in a dependent limb.

Abramson and Katzenstein\textsuperscript{23} reported that spontaneous fluctuations in the plethysmogram are characteristic for the hands but are absent or insignificant in the lower extremities. The present investigations go to prove that this difference is not due to any difference in vaso-

![Graph](image_url)

**Fig. 5.**—Plethysmogram of first toe of left foot (upper tracing) and first toe of right foot (lower tracing) simultaneously recorded to demonstrate differences in the height of spontaneous fluctuations as caused by differences in posture. The left limb was kept slightly dependent; the right limb was in a slightly elevated position. (For explanation see text.)

motor tone but is caused by differences in posture. The lower limbs obviously were tested in the dependent posture by these authors, which, as the present investigations show, accounts for the differences recorded. As we have pointed out,\textsuperscript{19} spontaneous changes in blood flow are characteristic for both the upper and the lower extremities, and if tested under identical conditions they are of the same magnitude in both upper and lower limbs.

The changes which occur both in digital volume and pulse volume as the subject changes from the horizontal to the vertical are easily followed in figure 6, which was obtained by tilting the subject on an x-ray examination table. At the signal, tilting is commenced and instantaneously there occurs a rise in digital volume similar to that obtained on inflating a cuff and obstructing the venous return. The digital volume rises approximately 0.3 cc., which means that the total volume of the digit is increased by about 2 per cent. The typical changes in both the height and the shape of the pulse volume, as described before, are observed. The pulse volume, which registered 0.03 cc. in the horizontal position, reaches barely 0.01 cc. in the erect position. The reverse is seen on returning from the horizontal to the erect posture. The digital volume decreases by the same amount and the pulse volume returns to its original height. All the changes registered both in pulse and digital volume with tilting and described for the normal were obtained in the sympathectomized limb as well.

Pulse Volume in Cases of Venous Obstruction and Thromboangiitis Obliterans: That the knowledge of the effect of changes in posture upon the plethysmographic appearances may not only be of academic interest but of practical value was made clear to us for the first time six years
EFFECT OF CHANGES IN POSTURE ON PERIPHERAL CIRCULATION

 ago when we tested a patient in whom extensive thrombosis of the veins of one leg had occurred following the injection of a quinine compound. This patient showed no clinical signs of arterial disease. He was tested like all other patients in the usual reclining position indicated in figure 1, A. However, the pulse volume showed all the characteristics of the pulse volume obtained in the normal subject with the volume at fast speed (fig. 8, A) was it realized that there was a definite pattern recorded which was the pulse volume. It was then that the thought occurred to us that the interference with the venous drainage might account for the picture. The leg was therefore elevated to an angle of 45 degrees and the pulse volume recorded in this posture featured the normal dicrotic pulse (figs. 7, B and 8, B).

Fig. 6.—The effect of changing the posture of a limb, as produced by tilting, on the peripheral blood flow in a normal subject. Note the increase in digital volume on tilting the patient from the horizontal to the erect posture, the decrease in pulse volume from 0.03 to 0.01 cc, and change in shape of pulse volume. (For explanation see text.) The "X" on the tracing indicates the point at which the plethysmogram was adjusted.

An identical picture was later obtained in a young woman in whom thrombosis of the inferior vena cava had been diagnosed (fig. 9). Here, too, although the pulse volume recorded in reclining posture was extremely small, it featured three well developed waves of almost equal size which at first sight were regarded as a fine tremor, but on close examination it was realized that the same pulse pattern was presented as that seen in the normal subject in the limb in pendent posture (fig. 7, A). Each pulse was composed of three well developed waves, the notch between each of them being very marked and reaching the base line between the first and second (dicrotic) wave, making it extremely difficult to pick out the individual pulses. Actually, the tracing was first considered to be produced by a coarse tremor and not to represent the pulse volume at all. Only on special scrutiny and on recording the pulse...
the erect posture. When the leg was elevated the normal shape in pulse volume was observed (fig. 9, B).

It had long been observed by us that the pulse volume in a high percentage of patients with thromboangiitis obliterans, when tested in the reclining posture, showed the pattern normally recorded in pendent posture. Such a tracing was demonstrated in figure 13 in our paper on the rate of blood flow published in 1943.22 Figure 10 of the present article was obtained from 2 patients with typical thromboangiitis obliterans.

The first patient (fig. 10, A) was a European man, 31 years of age, whose history had commenced six years previously with recurrent phlebitis and who developed typical intermittent claudication about two years later. He was seen for the first time four years after the onset of the phlebitis. At this time he had developed an ulcer on the first toe of his right foot. On clinical examination all pedal pulses were absent, the long and short saphenous veins showed definite but healed thrombosis, and there was a small ulcer on the great toe of the right foot. Both feet showed dusky red discoloration. Goldflam's sign was positive. The heart was normal on clinical examination and the blood pressure was 130/90. The fundi did not show any vascular
The nervous system and renal tract were normal. Special examination revealed complete block of the main arteries below the popliteal in both legs and the diagnosis of thromboangiitis obliterans was made.

The second patient was a young European man 27 years of age who had developed his first attack of phlebitis three years previous to examination. Ever since, he had had spells of thrombosis in one or other veins of any of the four extremities until two years before examination, when, for the first time, he developed intermittent claudication, numbness in both feet on walking, and symptoms of Raynaud's phenomenon in all extremities. He had been a heavy smoker always. He had not had enteric fever or any other illness. On examination, the heart was found to be normal, the blood pressure was 120/75, none of the peripheral pulses could be felt, and there were various cordlike segments of thrombosed veins in both legs. No trophic disturbances in the lower extremities were noted except for the absence of hair on both feet. The typical color changes were obtained, that is, pallor on elevation and dusky red in dependency. The central nervous system was normal, as were the fundi and urogenital tract. The diagnosis of thromboangiitis obliterans was made.

Figure 10, A and C illustrates the pulse volume of both these patients during rest in reclining posture. Again, the plethysmogram appears to record a fine tremor only, but on scrutiny a definite rhythm is noted, indicating that the pulse volume consists of three small but well developed waves. In the elevated po
Effect of Posture on Skin Temperature: There is no agreement in the literature as to the effect of changes in posture upon the peripheral circulation as judged by means of skin temperature measurements. Youmans, Ackeroyd, and Frank found a decrease in the temperature of the toes of normal subjects in the upright position, whereas Roth, Williams, and Sheard reported the opposite: that under environmental temperatures ranging from 23 to 30 °C., with the patient under basal conditions and free from sweating, the skin temperatures of the fingers and the toes decreased when the extremities were elevated and increased when

Fig. 9.—Pulse volume as recorded in a patient with thrombosis of the inferior vena cava. A. Reclining; B. elevated; C. pulse volume of first toe of left foot (upper tracing) and first toe of right foot (lower tracing) simultaneously recorded. Both in reclining position and during full dilatation. Patient had recent thrombosis of the left iliac vein. (Compare this figure with figure 4.)
they were pendent. The result was the same whether the changes in posture were obtained from changes in the posture of the body as a whole or from changes in the posture of the extremities themselves.

In this article we are not so much interested in the actual skin temperature during any particular posture but we wish to state that our findings confirm those of Roth, Williams, and Sheard.35 Our interest centers around the response of the skin temperature, in limbs tested in different postures, to induced changes in vasomotor tone, as produced by body heating. We have reported previously upon the effect

Fig. 10.—Plethysmogram in two typical cases of thromboangiitis obliterans. A and C. Reclining; B and D. elevated. Note that the appearance of the pulse in A and C is that recorded in the normal subject in the sitting or standing posture.
of body heating on the peripheral blood flow as judged by skin temperature and plethysmographic investigations. As the central vasomotor tone is released (fig. 11), the skin temperature rises within thirty minutes to the normal vasodilatation level (32 C.), the pulse volume increases to at least 0.02 cc. and the digital volume increases depending upon the state of the vessels prior to body heating. At the same time the rate of blood flow per minute for 100 cc. of tissue reaches values between 80 and 100 cubic centimeters. All these findings refer to patients in the reclining position. Quite a different response may be recorded in a limb tested in a different posture. Figure 12 illustrates the point in question. The chart shows the response of the skin temperature to body heating in a patient in whom the right leg was kept hanging down while the left leg was elevated. As can be seen, there is a marked difference between the response of the skin temperature in the two legs. In the pendent limb the skin temperature rise, once initiated, is rapid and within twenty minutes reaches the normal vasodilatation level, registering a rise of 11 degrees C. In the elevated limb the rise in skin temperature sets in after the same time interval but, in contrast to the pendent limb, 28 C. only is recorded after twenty minutes’ body heating. After thirty minutes’ body heating, when the skin temperature should have reached 32 C., it registers only 27 C. That this difference in the response of the skin temperature to body heating was not due to organic arterial disease but was caused only by the difference in posture could be demonstrated beyond doubt by reversing the posture of the two limbs, whereupon the same result is obtained; that is, the temperature of the now pendent limb reaches 32 C. easily, while the elevated limb shows hardly any skin temperature response. Furthermore, if at the end of the test the elevated limb is lowered, the skin

![Graph](image-url)

**Fig. 11.**—Graph prepared from continuous plethysmogram as obtained during body heating, demonstrating the normal response of the peripheral blood flow to the ablation of sympathetic tone. Rate of blood flow in cc. per minute for 100 cc. tissue, as calculated from venous congestion tests.

**Fig. 12.**—Effect of posture on the response of the skin temperature to the release of sympathetic tone as produced by body heating.
temperature rises rapidly and reaches the normal vasodilatation level within a few minutes.

These observations are of considerable importance since skin temperature readings are often employed for testing the patency of the peripheral vascular tree and a rise in skin temperature to 32 C. is regarded as the minimum vasodilatation level indicating normal circulation. The fallacy of this statement in other respects has been pointed out by us previously.\textsuperscript{19,36} It was then demonstrated that a normal response of the skin temperature by no means precludes the possibility of organic arterial disease. The present investigations demonstrate that even slight changes in posture affect the speed and the ultimate level of the skin temperature rise accompanying reflex vasodilatation. In the elevated limb the skin temperature response is diminished and retarded and may never reach the normal vasodilatation level, and this in a limb which is known to be normal. In pendent posture, however, the normal vasodilatation level is reached easily within thirty minutes, usually much earlier. By elevating the limb the skin temperature in a normal subject can be induced to simulate the response characteristic of organic occlusion. The reverse holds good, too, since in a leg with advanced occlusion the skin temperature can be made to reach the normal vasodilatation level by adopting a more dependent posture.

Recording the skin temperature only, one gets the impression that with elevation of the extremities body heating does not, or only partially, results in reflex dilatation. Indeed, this was the conclusion at which Uprus, Gaylor, and Carmichael\textsuperscript{26} arrived. On consulting the plethysmogram, however, one realizes that this cannot be correct (fig. 13). The pulse volume, independent of the posture and in contrast to the skin temperature, reaches the vasodilatation level easily within thirty minutes. Actually, the pulse volume reaches considerably higher values in the elevated limb (figs. 13 and 14). One is confronted, therefore, with the apparently paradoxical situation that in elevated limbs after thirty minutes' body heating the skin temperature is such as would indicate marked interference with the peripheral circulation, while the pulse volume actually is well above the normal minimum vasodilatation level, giving proof of the fact that the arterial circulation is entirely adequate. The plethysmographic findings, therefore, lend no support to the conclusions drawn by Uprus and co-workers\textsuperscript{26} that the diminished response in the skin temperature is due to incomplete reflex vasodilatation, but prove that the arterial tree is dilating in the normal fashion. It is the difference in the venous drainage which brings about the diminished rise in skin tem-

\begin{figure}
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\caption{The effect of posture on the response of the peripheral circulation to the release of sympathetic tone as produced by body heating. Interrupted lines represent normal response with the patient in reclining position; uninterrupted lines, the response with limbs elevated. Note the difference in skin temperature and higher pulse volume in the elevated limb during full dilatation.}
\end{figure}
perature to body heating. No better example could be found to demonstrate the caution which has to be exercised when translating skin temperature measurements into terms of arterial blood flow. The skin temperature is a function of the venous drainage to a degree hitherto unrecognized. The clinical implications of this observation in such conditions as iliac thrombosis and arteriovenous fistula are obvious and will be dealt with separately. It is essential to record the posture whenever skin temperature readings are taken and no doubt some observations reported in the literature lose much of their significance in the light of these data.

From these observations it must be clear that any clinical condition which interferes with the venous return from the extremities must of necessity produce an increase in skin temperature and such a limb should warm more quickly on body heating. Indeed, in contrast to the writings of some authors, 27-21 we have found, in keeping with the findings which have been stated, that in the vast majority of cases of unilateral venous thrombosis the affected limb is warmer and not colder than the normal limb. Actually, this has been observed by many of our patients themselves. Not only is the actual skin temperature increased, but it has been found that on body heating the skin temperature of the affected limb rises much more quickly than that of the normal limb, and the ultimate skin temperature of the affected limb often is higher than in the normal limb.

These findings are not merely of academic interest, as the following case history demonstrates.

A Jewish man, aged 38 years, who had symptoms suggestive of intermittent claudication in the left leg, was referred to us. The previous investigator had found a definite difference in the response of the skin temperature of the two lower limbs to reflex vasodilatation. The left limb warmed up more slowly than the right one, although the skin temperature eventually reached the normal vasodilatation level in both. Clinically, there was a difference in the strength of the pedal pulses, but there were no signs of arterial disease. On the strength of the difference in the skin temperature response to reflex vasodilatation, the previous investigator diagnosed early thromboangiitis obliterans in the left leg. When we examined the patient the findings of the previous examiner could be confirmed: the skin temperatures increased more rapidly in the right leg than in the left on body warming, and there was a difference in the strength of the arterial pulses in the two limbs. However, the arterial circulation in both legs was normal, as judged by plethysmographic examination. When it could be proved that there was interference with the venous drainage, it was obvious that it was not the left limb which showed a diminished response to reflex vasodilatation, but that it was the right limb which warmed up more quickly. When this patient was re-examined four years later, the plethysmogram still gave normal values in both limbs. There were no signs of any arterial disease. The difference in the pedal pulses was explained as an anatomic abnormality. We do...
know that in 12 to 14 per cent of normal subjects the arteria dorsalis pedis may be diminished or absent, while the posterior tibial may be absent in about 2 to 5 per cent of cases.²⁹, ³⁰

**Discussion**

Before entering into any discussion of the results, a decision must be made as to whether the changes in the peripheral circulation observed with alterations in posture as described in this article are caused by differences in hydrostatic pressure and venous drainage or have to be attributed to sympathetic reflex phenomena. Since the changes could also be recorded in the sympathectomized limb, it appears that a central or spinal vasomotor reflex can be excluded and that the observed reactions must be explained in terms of alterations in the venous drainage and hydrostatic pressure.*

In the past the results of both skin temperature readings and plethysmography have been interpreted solely in terms of function and patency of the arterial tree. The influence which may be exercised by changes in venous drainage on the skin temperature and the plethysmographic appearances have hardly been considered. One method by which the venous drainage in the normal person may be altered is by changing the posture. Few investigators, however, have examined the effect of posture on skin temperature and none its effect on the plethysmographic appearances. Such skin temperature studies as are available are contradictory. Roth, Williams, and Sheard²⁵ found that elevation will decrease, and dependency increase the skin temperature, while Youmans, Ackeroyd, and Frank³¹ reported contrary results. Our own investigations are in full agreement with those of Roth and co-workers. However, we were not so much concerned with the actual skin temperature at different postures, as with the effect of posture upon the response of the skin temperature to body heating. The latter is rather important since body heating is generally used as a test for assessing the state of the peripheral circulation.

* However, it is necessary to state clearly that this does not imply that differences in vasomotor tone between the upper and lower extremities which we explain as being due to differences in posture are not due to central sympathetic activity.

Gibbon and Landis,"³¹, ³² who popularized this test, were of the opinion that a rise in skin temperature to 32 C. within thirty to thirty-five minutes "definitely excludes the possibility of obliterative structural disease of the arteries," a criterion which is generally accepted. Jahsman and Durham³³ state that such a response excludes the possibility of obliterating structural disease of the artery. However, in a previous paper¹⁹ we brought forward evidence that skin temperatures may still give "normal" values when the blood flow is as much as 30 per cent below normal, as judged by plethysmography. The correctness of the plethysmographic readings was proved subsequently by postmortem examinations.

In the present paper it is demonstrated that even if the blood flow, as judged by plethysmography, is normal, the criteria of Gibbon and Landis are still not acceptable without further qualification. By merely elevating a normal limb the response of the skin temperature can be modified to such an extent that with body heating it may reach only 27 or 28 C. during the thirty minutes normally allowed to reach the vasodilatation level. The same limb in a horizontal or slightly pendent posture will easily give the "normal" response, that is, reach 32 C. Uprus, Gaylor, and Carmichael²⁴ had already observed this difference and they concluded that, in the elevated limb, body heating is not capable of overcoming vasoconstrictor tone. By investigating this question with our plethysmographic method, we could clearly demonstrate that, despite this difference in skin temperature, there is no difference between the blood flow in the elevated and the pendent limb and that the vasoconstrictor tone is released simultaneously in both, irrespective of the posture. The moment the necessity of the body to dissipate heat arises, vasomotor tone diminishes, whether the limb is elevated or not. Indeed, it could be demonstrated that after thirty minutes' body heating the pulse volume is actually larger during elevation than during dependency, and this at a time when the skin temperature has failed to reach the normal vasodilatation level. There may be a deficit of up to 8 degrees C. Hence, the failure of the skin temperature to rise cannot be due to a
failure to overcome vasoconstrictor tone in the elevated position. The plethysmographic investigations suggest very strongly that such differences as are observed in the skin temperature are due to changes in the hemodynamics in general and changes in the venous drainage in particular, as produced by changes in posture.

During elevation there occurs a fall in venous pressure, an emptying of the larger veins, and a drainage of Wollheim's subpapillary venous plexus. The blood returns hastily through collapsed veins. Our investigations therefore suggest strongly that the skin temperature is to a large degree a function of the venous drainage. The fact that the skin temperature in the elevated limb does not rise with reflex body heating to the normal vasodilatation level is due, then, to facilitation of the venous drainage during elevation. It may be concluded that it is not only the amount of blood but also the time which the blood takes to flow through the subpapillary venous plexus and through the small veins which determines the ultimate skin temperature. If the blood is rushing through these channels, as in the elevated limb, then there is no time for the blood to give off heat and transmit its temperature to the surrounding tissue and the skin temperature will be relatively low. The contrary occurs in the pendent limb where the slightest release of the arterial tone accompanied by the pooling of blood causes a rapid increase in skin temperature. On body heating, therefore, the skin temperature in a pendent limb rises rapidly and reaches the normal vasodilatation level before there occurs full vasodilatation of the vessels. While in the elevated position the skin temperature of the limb will not reach the normal vasodilatation level within thirty minutes of body heating in a person with normal arteries; in the pendent limb the skin temperature easily reaches the normal vasodilatation level even if there is already advanced organic arterial interference. Posture, therefore, is an important factor in determining the actual skin temperature and the results of the present study demonstrate clearly the limitations of skin temperature readings in assessing the peripheral circulation. Whenever skin temperature readings are reported the posture should be stated, otherwise unreliable or incorrect conclusions will be drawn from such investigations.

In the pendent posture, with the arteries moderately dilated, the skin temperature of the feet would always be in the neighborhood of 34 to 35 C.; dissipation of heat would therefore be maximal. Obviously this is not in the interests of an economical body temperature regulation. To overcome this effect of the upright posture, therefore, a high vasomotor tone in the lower extremities develops to reduce blood flow and heat loss. The high vasomotor tone of the lower extremities therefore is explained as the result of man's assumption of the upright posture which, by virtue of its hemodynamic effect in general and interference with the venous drainage in particular, militates against the use of the lower extremities in body temperature regulation. As we have pointed out previously,19 under ordinary conditions the blood flow through the lower extremities is mobilized for body temperature regulation only when the capacity of the upper extremities has been fully exhausted.

These findings have a definite bearing on the understanding of the clinical picture of such conditions as varicose veins, venous thrombosis, scleroderma, and arteriovenous fistula, and on the management of the edematous ischemic limb. There is always some hesitation in elevating the edematous and ischemic limb to promote increase in lymphatic drainage because with elevation there occurs a decrease in skin temperature. The results of the present study indicate that this does not necessarily mean that there is a diminution in arterial blood flow. The contention of Bazett,30 that in the elevated limb the reduced bore of the collapsed veins increases the resistance to the capillary blood flow, is not borne out by our results since the pulse volume in the plethysmogram is actually higher in the elevated than in the horizontal or dependent limb. Accordingly, one need not hesitate to elevate the edematous limb to increase the flow of lymph, decrease interstitial pressure on the capillaries, and promote capillary blood flow.

It appears, too, that at least part of the different response of the lower extremities to
sympathectomy can be attributed to the difference in posture. Sympathectomy abolishes the higher vasomotor tone normally observed in the lower extremities. The veins being sympathectomized as well as the arteries, relaxation occurs in both, with but one difference; that the veins with their poor muscular coat do not reacquire that degree of tone seen in the arteries sometime after sympathectomy. Hence, following sympathectomy there occurs pooling of blood in the veins and slowing of venous return which, apart from any increase in the arterial circulation, will, as we have seen, lead of its own accord to an increase in skin temperature. Normally, this pooling of blood does not assume pathologic dimensions since it is partly counteracted by the muscular activity. This can be proved by investigating the effect of sympathectomy in subjects in whom the venous return is not assisted by muscular activity. Pooling of blood becomes marked and of pathologic significance. This we have observed in a number of patients with poliomyelitis in whom there was almost complete paralysis and atrophy of the muscles of the lower leg with marked vasospastic disturbances. Such patients develop marked edema following sympathectomy because the pooling of blood is not counteracted by the muscular pump. Therefore we have discontinued performing sympathectomy in the paralyzed limb with marked atrophy of the muscles, even if it can be demonstrated that the circulatory disturbances are entirely vasospastic in nature.

In the past we always interpreted the height of the pulse volume in the digital plethysmogram in terms of patency of the arterial tree. The present account demonstrates the profound effects of posture on both the height and the shape of the pulse volume. The knowledge of these changes is of practical interest. It has been noted that in many cases of thromboangiitis obliterans, in some cases of thrombophlebitis, and in some cases of thrombosis of the inferior vena cava, the normal dicrotic pulse shape is replaced by three or four equally high elevations, when tested with the subject in the usual reclining posture. In the normal person a similar pattern may be produced if if the test is made with the individual in the erect or sitting posture. This suggests strongly that it is the changes in the hemodynamics in general and interference with the venous drainage in particular which account for the changes observed. Knowing that venous thrombosis is characteristic in thromboangiitis obliterans, it appears justified in the light of these observations to interpret such changes in the shape of the pulse volume in these cases as the result of venous involvement. It may thus be possible in a case of suspected thromboangiitis obliterans, in which no signs or symptoms of venous involvement are manifest, to determine whether venous thrombosis has occurred to any extent, thus adding considerable weight to the presumptive diagnosis in a doubtful case. Such observations would also be particularly important in patients in their forties in whom the differential diagnosis between arteriosclerosis and thromboangiitis obliterans may present considerable difficulties. However, further studies will be necessary.

The observed postural changes in the plethysmographic appearances in general and of the pulse volume in particular make it obligatory, too, that the posture always be indicated whenever the plethysmogram is consulted. It is therefore important to standardize the posture in which tests are carried out in order to get comparable results. In the past we have carried out all our tests in the position indicated in figure 1, using the couch and accessories developed in our laboratories. This has proved most convenient in many thousands of tests during the last ten years. It is likely that, with the development of portable plethysmographs, more commonly employed for assessing the peripheral circulation, as its merits deserve. We would suggest, therefore, that investigators adopt the posture indicated as standard. A similar plea may be made with regard to skin temperature readings, as is evident from the investigations reported in this paper.

The suggested position has the advantage that patients with cardiac decompensation, in whom one is very often called upon to investigate the peripheral circulation, can easily be tested. In the horizontal posture difficulties
would arise in patients with any degree of orthopnea.

There is no doubt that any investigation of the peripheral circulation without due respect to posture loses much of its significance in view of the present investigations, and many of the controversial results may be explained on this basis.

The present investigations may be of some significance, too, in evaluating such therapeutic measures as make use of changes in posture, such as vascular exercises or Saunder's oscillating bed. Further investigations with our method, as outlined herein, should furnish valuable results as to the efficacy of such methods in improving the peripheral circulation.

**SUMMARY AND CONCLUSIONS**

1. The effect of posture on the peripheral blood flow has been investigated by means of the Goetz digital plethysmograph and skin temperature readings.

2. It is demonstrated that even slight changes in posture have marked effect on the plethysmographic appearances. Both the height and the shape of the pulse volume are affected.

3. With the subject in the erect posture the height of the pulse volume is only a fraction of that recorded in the elevated limb.

4. The changes in the shape of the pulse volume with changes in posture are marked. In the elevated limb the pulse volume tends to be monocrotic. With the subject in the erect posture the dicrotic wave is pronounced and is usually followed by one or two more waves. The notch between the main elevation and the dicrotic wave reaches the base line.

5. With the limb in the dependent posture all changes in digital volume, both spontaneous and those induced by extrinsic and intrinsic stimuli, are greatly diminished. In the elevated position they are very much pronounced.

6. The changes described are recorded irrespective of whether the posture of the limb only or that of the whole body is altered.

7. The changes in the plethysmographic appearances resulting from changes in posture are recorded in the sympathectomized limb and therefore are not due to changes in the vasomotor tone but to alterations in the hemodynamics and venous drainage.

8. In patients with obstruction of the venous return and in some patients with thromboangiitis obliterans, the pulse volume with the subject in the reclining posture assumes the shape normally seen only in the dependent limb. Conversely, interference with the venous return may be suspected if the pulse volume tested when the individual is reclining shows the features normally seen only in the erect position. The clinical importance of this finding in determining the patency of venous circulation is stressed.

9. The effect of changes in posture on the skin temperature is discussed. It is demonstrated that in the elevated limb the skin temperature does not reach the normal vasodilation level on body heating. This is not due (as had been thought by previous authors) to a failure in the release of sympathetic tone. Plethysmography shows that in the elevated posture the vessels dilate in the usual manner. The pulse volume records normal values, despite the lower skin temperature. This provides an excellent example of the superiority of digital plethysmography over skin temperature readings in assessing the state of the peripheral circulation.

10. It is demonstrated that this diminished response in skin temperature is due to the change in venous drainage. The state of the venous drainage, therefore, is almost as important a factor in determining the skin temperature as is the arterial supply.

11. The clinical importance of these findings is discussed in relation to the better effect of sympathectomy in the lower extremities and in relation to the indications for sympathectomy in patients with marked wasting of muscles (poliomyelitis).

12. In the past the results of both skin temperature readings and plethysmography have been interpreted solely in terms of function and patency of the arterial tree. This concept has to be revised. The study of the effect of changes in posture on the peripheral circulation demonstrates clearly that the venous limb of the vascular tree plays a part unrecognized hitherto.
EFFECT OF CHANGES IN POSTURE ON PERIPHERAL CIRCULATION

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