THE MEASUREMENT OF SYMPATHETIC VASOCON- STRICTOR ACTIVITY IN THE LOWER EXTREMITIES¹

By JOHN J. MORTON AND W. J. MERLE SCOTT

*(From the Department of Surgery, the University of Rochester School of Medicine and
Dentistry, Rochester, New York)*

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INTRODUCTION

During the last ten years the medical profession has shown a lively interest in the vascular diseases of the extremities. The attitude has changed from a feeling of hopelessness to a desire for more effective therapeutic measures. It has likewise become apparent that accurate diagnosis of the actual condition present in any individual case is often a matter of the greatest difficulty. The work of Allen and Brown (1) has materially helped in untangling the confusion in this group of conditions.

At the present time the majority of our tests indicate only the adequacy or failing of the circulation. The color of the extremity at the horizontal, in dependency, at elevation almost to the vertical, and after exercise is very important. The time of color return after pressure has blanched an area indicates the efficacy of capillary circulation. The blushing test following removal of a tourniquet often tells fairly accurately the level below which the limb is in danger. The oscilometer may show that pulsation is still present though it can no longer be palpated. The salt solution intradermic wheals help us to judge the degree of circulatory impairment. The measurement of surface temperatures by thermocouple readings, and the rapidity of return of such temperatures, after constricting the circulation, give data of value. The only method so far available to estimate the relative amount of vasoconstriction is the intravenous typhoid vaccine reaction

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introduced by Brown (2). This procedure gives a general reaction of considerable severity. If the surface temperatures of the extremities are recorded by thermocouple readings during this time an indication of the amount of vasospasm is evident. If the disease is purely organic obstruction practically no change takes place in this vasomotor index.

It has long been known that there is a vasodilatation under general anesthesia. The loss of heat from this source makes it necessary to keep the patient well covered throughout an operation. This is a general response of the peripheral vascular network. It occurred to us that there might be a vasomotor response following spinal anesthesia. It was relatively easy to test the cutaneous temperatures of the feet of patients under this form of anesthesia.

METHODS AND RESULTS

The first tests were made on a group of patients with normal vascular systems as far as could be determined by the usual clinical examinations.² These patients suffered from such conditions as gallstones, ventral hernias, bilateral inguinal hernias, and chronic appendicitis. They were all in good condition and the operation was in every case an operation of election. Spinal anesthesia was chosen usually for technical advantages. The vasomotor response of these people who were in good general physical condition with normal vessels was almost uniform. Surface temperatures were recorded at identical points on the soles and dorsal surfaces of the feet and on plantar surfaces of the great toes of both sides. The feet were exposed for twenty minutes and the skin temperatures allowed to adjust themselves, several readings being taken to establish a base line. The room temperature was kept as constant as possible at about 23°C., and care was taken to exclude air currents. A constant temperature room was not available. Readings were then made as soon as possible after spinal anesthesia had been induced and at frequent intervals thereafter. The table was

² The surface temperatures were determined by the thermocouple method. An improved apparatus for such measurements was devised and has been briefly described in the *Journal of the American Medical Association*. All of the later determinations were made with this instrument, the *Dermatherm*.

tilted from five to ten degrees within a few minutes after the lumbar puncture.

There is a fluctuation in the surface temperatures of normal feet, at times the readings on the same foot varying as much as 2°C . There is rarely more than one degree in difference between the two sides. The sole regularly has a higher surface temperature than the under surface of the great toe, the former being anywhere from 3° to 8°C . higher than the latter. The average readings for twenty-two cases before opera-

FIG. 1. THE VASOMOTOR RESPONSE OF NORMAL VESSELS FOLLOWING SPINAL ANESTHESIA

tion were $24.7 \pm 3^{\circ}\text{C}$. for the toes and $30.25 \pm 3^{\circ}\text{C}$. for the soles. The height of the peak which the surface temperature reached after spinal anesthesia was almost the same for both soles and toes, $34.2 \pm 2^{\circ}\text{C}$. and $34.5 \pm 1.5^{\circ}\text{C}$. respectively in twenty-two observations. There is thus a much larger proportionate rise for the surface temperature of the toes than for that of the soles after spinal anesthesia. The reading is so constant that it undoubtedly represents the maximum vasodilatation response for the normal vessels of the lower extremities (fig. 1). Thirty-three degrees centigrade is its lower limit in the toe (named by us "normal vasodilatation level"). For purposes of estimating the

element of organic obstruction in a vascular disease the maximum surface temperature reached after sympathetic paralysis is subtracted from this figure and the difference is the "obstruction index."

The chief exceptions so far noted to the above normal reactions are in patients with fever; or in those with advanced carcinoma. Patients with fever have the surface temperatures of the feet already at the maximum vasodilatation level. Patients with advanced carcinoma strangely enough also show high surface temperature readings for the extremities. In three such patients on whom palliative operations

FIG. 2. AN EXCEPTION TO THE RULE FOR NORMAL VESSELS IS SEEN IN ADVANCED MALIGNANCY

were performed under spinal anesthesia, the surface readings before anesthesia registered as an average at 32.5°C. Following spinal anesthesia there was a steady drop of surface readings in two cases so that the feet were from two to five degrees C. colder after operation than before (fig. 2). In the third case there was a faint rise above the preoperative level but it was only transient. The temperatures remained approximately the same after the spinal anesthesia in this case.

We have also had an opportunity to test the response to spinal anesthesia in certain types of vascular disease of the extremities. Tests have been made on cases of endarteritis obliterans with and without vasospasm, on thromboangiitis obliterans with vasospasm, on

arteriosclerotic diseased vessels; but not as yet on true Raynaud's disease. The tests have been made on patients with these conditions both before and after lumbar ganglionectomy, and in some instances where only a unilateral operation had been performed. Cases typical for each group studied will be cited below to illustrate the usefulness of the method.

In a typical case of endarteritis obliterans where pulsation could not be made out below the left femoral artery, but was present though diminished in the vessels of the right foot, the surface temperatures of

FIG. 3. Diseased vessels vary in their vasomotor reaction depending on the condition. The left toe was the cause of complaint in this patient but even the right side shows only a moderate reaction. Pulsation in vessels of foot—absent on left, feeble on right.

both feet and toes were approximately equal. Following spinal anesthesia there was a drop in cutaneous temperature on the left where the vessels were diseased, and a rise on the right side where the vessels gave evidence of less involvement. It was apparent that vasospasm was not an important factor in this case and that operation on the sympathetic nerves would not be successful. The lesion was probably an obliterative endarteritis on a syphilitic background (fig. 3).

A similar case of endarteritis of syphilitic nature showed popliteal

pulsations on both sides and pulsations in the arteries of the left foot, but no pulsation could be made out in either the dorsalis pedis or posterior tibial artery on the right. The right sole and great toe were colder than the left on thermocouple readings and after spinal anesthesia, although the left foot responded with an abrupt and sustained rise in temperature, the right response was less in degree and slower. The right side reached the normal vasodilatation level but the left side had an "obstruction index" of 2° . This test showed that there

FIG. 4. In this case of endarteritis the right foot caused the trouble. The solid lines are for the right sole and toe respectively and the dotted lines for the left sole and toe. It is apparent that the readings for the right sole and toe are about 2°C . colder than the corresponding left readings. After spinal anesthesia the right side shows a fair vasomotor response but not as good as that of the more nearly normal left foot.

was a moderate vasospastic element present together with definite obstruction (fig. 4).

In a diabetic patient with obliteration of the arteries and a previous mid thigh amputation on the left, the question of palliation for impending gangrene of the right foot became urgent. Surface temperature readings indicated that the great toe was warmer than the sole. But after spinal anesthesia the toe showed scarcely any response while the sole gave a decided surface temperature rise. From this study it seemed that the vessels supplying the sole of the foot showed vasoconstriction and reacted to the normal vasodilatation level. The toe, however, showed no vasoconstriction but an "obliteration index" of 2° .

We interpreted this as meaning that the main arterial channels to the toe were completely obstructed. The smaller arteries showed no

FIG. 5. In this case of arteriosclerosis the surface temperature of the great toe is higher than normal but the response is not marked. The sole shows a much better reaction.

FIG. 6. The contrast between the complete vasodilatation on the right side which has had the lumbar sympathetic ganglia removed and the left unoperated side is striking. The surface temperature response of the unoperated side to spinal anesthesia indicates that there is a large element of vasospasm in the vascular condition on that side.

spasm, possibly due to diminished intravascular pressure. Simple ligation of the popliteal vein was done in the hope of producing better peripheral distribution of the arterial blood (3) (fig. 5).

A patient with characteristic symptoms of thromboangiitis obliterans, more marked on the right, was tested with typhoid vaccine, and gave evidence of vasospasm. Right lumbar ganglionectomy was done with marked lasting relief on the right side. During the year, however, the condition progressed on the left side. This patient presented an ideal case for comparison of the operated and non-operated sides. The surface temperature showed that the sympathectomized limb had high readings on the right sole and great toe as contrasted with those on the left which were 6° to 10°C. colder. When spinal anesthesia was given there was a marked rise in surface temperature on the cold left side while the right side was already within 1° of the normal vasodilatation level and showed no increase. It may be necessary to remove the left lumbar sympathetic chain in order to arrest the progress of the disease on that side (fig. 6). The right side which was much the worse originally is now considerably better than the left. We are studying the surface temperature response to vasodilating drugs in this same patient. There is an excellent opportunity to thus compare the drug action with the known effective paralysis of sympathetic overactivity.

DISCUSSION

Spinal anesthesia acts as an effective temporary chemical block between the spinal cord and the peripheral nerves. It shuts off all motor, sensory and sympathetic impulses and allows the maximum release from their action. Consequently sympathetic inhibition as indicated by peripheral vasospasm is no longer active. This results in a maximum vasodilatation which manifests itself by a uniform rise in surface temperature of the extremities. The surface temperature readings for normal individuals under spinal anesthesia show that there is a close agreement and a narrow range of variation for complete vasodilatation. This furnishes an average surface temperature top-level which may be used as a gauge against the surface temperature readings in patients with abnormal peripheral vessels under similar conditions. By testing various areas of the limb it is possible to judge the degree of occlusion and spasm for the vessels and anastomotic circulation supplying that area. The test is easily carried out in a relatively short period of time which makes it contrast favorably with

the typhoid vaccine intravenous reaction. There is relatively little danger in the low spinal anesthesia given with all the care essential to its induction. The element of spasm can be readily separated from the mechanical obliteration of the lumen by using this method. The reaction is one which is not general in nature but is localized to the part under investigation. Consequently, the method gives a more selective response than one which is only part of a general systemic disturbance.

In normal individuals there is a varying vasomotor activity in different parts of the body. Such people at least under slight emotional stress such as the anticipation of an operation have a sympathetic vasoconstrictor gradient in the extremities. Whereas the hands and thighs regularly register at the normal vasodilatation level, at about the knee a varying degree of vasoconstriction, increasing peripherally, becomes evident. Thus it has been our experience in patients without vascular disease, that the toe is the coldest area in the extremities. No comparison has been made between the individual digits; the great toe alone was usually tested. Spinal anesthesia obliterates this normal vasoconstrictor gradient.

In vascular disease there are three types of reaction to spinal anesthesia.

1. There may be no change in the gradient, indicating entire absence of vasospasm.
2. There may be complete obliteration of the gradient indicating that the vascular symptoms are entirely dependant on vasospasm.
3. There may be only a partial obliteration of the gradient, the peripheral surface temperatures rising significantly but not reaching the normal vasodilatation level. This indicates a mixture of vasospasm and obliteration as responsible for the clinical syndrome.

In the first type of vascular disease reaction mentioned above, intervention upon the sympathetic nervous system is valueless. This group includes particularly many cases of the senile and diabetic forms of arteriosclerosis.

In the second type, operative interruption of the sympathetic innervation will permanently release the vasoconstriction which was temporarily overcome by spinal anesthesia.

In the third type a more extensive experience with these patients

will be necessary before definite conclusions can be drawn as to the best form of therapy. At present each case showing both obstruction and spasm is a problem in itself. It will be particularly desirable to correlate the relative proportions of mechanical obliteration and spasm with the therapeutic results obtained.

The results of paralyzing the sympathetic vasoconstrictor nerves are worthy of mention in another condition, not primarily a vascular disease. In view of the possible relationship between sympathetic overactivity and chronic non-specific arthritis (arthritis deformans) as recently reported by Rowntree and Adson (4), a study of the vascular response to spinal anesthesia in such patients was made. In general the vasomotor gradient was completely obliterated after spinal anesthesia, the periphery reaching the normal vasodilatation level just as in the normal control subjects. We are unable to conclude from our data whether vasoconstriction plays a rôle in the continuation of the disease. Further studies will be necessary to show whether the vasoconstriction is more continuously persistent in these arthritic patients than it is in normal individuals.

Rarely does intrinsic disease of the blood vessels in the extremities require amputation in the arms or above the lower third of the thighs. On the other hand if it is carried out below the knee and especially in the foot the progress of the disease often requires reamputation at a higher level. It is interesting that this point where the circulation to the skin is almost always valid coincides with the upper limit of the vasomotor gradient. The latter may be a factor which influences the nutrition of the flaps or it may influence the development of thrombosis within the vessels as is known to occur at times in Raynaud's disease and in thrombo-angiitis obliterans. In the future any clinical or pathological study of vascular disease in the lower extremity should consider this normally acting and probably pathologically over-acting vasoconstriction which begins at about the knees and increases distally and which can be entirely abolished by anesthesia of the sympathetic nerves to the part.

SUMMARY

In vascular diseases of the peripheral vessels it is essential to estimate the proportion of organic occlusion and vascular spasm.

The only test for vascular spasm in current use at present is the intravenous injection of the foreign protein typhoid vaccine.

The surface temperature response of the affected limb is part of the general reaction to the foreign protein.

A more desirable test which is not a general reaction but selective for study of the vessels of the lower extremities is here offered.

In individuals with normal peripheral vessels a varying but progressive vasoconstriction from the knees to the toes can be demonstrated ("vasoconstrictor gradient"). After spinal anesthesia, there is usually a rapid rise in surface temperature on the feet so that all surface areas of the body reach approximately the same level ("normal vasodilatation level").

Exceptions to this have so far been seen in patients with fever and in cases of advanced carcinoma.

In such exceptions, the surface temperature readings of the distal vessels start much higher than normal. The vasodilating action seems to be working almost at its maximum.

Chronic non-specific polyarthritis shows a vasomotor gradient, which may or may not play a part in continuing the disease.

The use of spinal anesthesia gives a selective effect on the vasoconstrictors of the vessels of the lower extremity.

By its use the degree of vasoconstrictor activity in the lower extremities can be accurately measured by the rise in the surface temperature of the feet.

Lesions on a solely mechanical basis show no rise in the surface temperature readings of the feet after spinal anesthesia. The difference between the readings in these cases and the normal vasodilatation level is a measure of the element of mechanical occlusion (occlusion index).

The purely obliterative types can thus be readily distinguished from the vasospastic. When the two elements are mixed the relative proportions of spasm and organic occlusion can be estimated in any individual case.

The test is simple, safe, rapid and localized to the part under study.

Surface temperatures show rapid changes in normal individuals under inhalation anesthesia.

This offers a possibility for a simple test for vascular lesions of the upper extremity.

Inhalation of nitrous oxide and oxygen combined with surface temperature readings might be of value in estimation of vasospasm in such cases.

This has not been used extensively so far, as we were anxious to use tests of selective and not of general nature.

We hope to further simplify the tests for vasoconstrictor activity by modifying the inhalation method when we have once satisfied ourselves regarding the basic process involved.

Since writing this paper an interesting study by Dr. James C. White (5) has appeared. He also advocates blocking the sympathetic nerves to determine the presence or absence of vasoconstriction.

CONCLUSIONS

The importance of deciding whether a given peripheral vascular disease is due to vasospasm, occlusion of the lumen, or combination of the two is recognized.

Spinal anesthesia is offered as a test which will simplify the differentiation of these elements in the lower extremities.

BIBLIOGRAPHY

1. Allen, E. V. and Brown, G. E., *Am. J. Med. Sci.*, 1927, clxxiv, 319. Erroneous Diagnosis of Raynaud's Disease in Obliterative Vascular Disease (Thromboangiitis Obliterans) I—Vasomotor Disturbances Simulating Raynaud's Disease.
- Allen, E. V. and Brown, G. E., *Am. J. Med. Sci.*, 1927, clxxiv, 329. Erroneous Diagnosis of Raynaud's Disease in Obliterative Vascular Disease (Thromboangiitis Obliterans) II—Thromboangiitis Obliterans of the Lower Extremities with Pulsating Pedal Arteries.
2. Brown, G. E., *J. Am. Med. Assoc.*, 1926, lxxxvii, 379. The Treatment of Peripheral Vascular Disturbances of the Extremities.
3. Morton, J. J. and Pearse, H. E., *Ann. Surg.*, 1928, lxxxviii, 233. Temperature Effect of Popliteal Vein Ligation in Thromboangiitis Obliterans and Arteriosclerosis.
4. Rowntree, L. G., and Adson, A. W., *J. Am. Med. Assoc.*, 1927, lxxxviii, 694. Bilateral Lumbar Sympathetic Ganglionectomy and Ramisectomy for Polyarthritis of the Lower Extremities.
- Rowntree, L. G. and Adson, A. W., *J. Am. Med. Assoc.*, 1929, xciii, 179. Polyarthritis—Further Studies on the Effects of Sympathetic Ganglionectomy and Rasmisectomy.
5. White, James C., *J. Am. Med. Assoc.*, 1930, xciv, 1382. Diagnostic Blocking of Sympathetic Nerves to Extremities with Procaine.