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VASODILATOR FIBERS IN THE HUMAN SKIN

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Reports on vasodilator fibers in the human skin have not been in general agreement concerning either their existence or their relative functional significance (1-6). In a recent review on sympathetic surgery (7), the interruption of vasodilator fibers was cited as a possible cause for the limited benefit that occurs after sympathectomy for certain types of peripheral vascular disease. It seemed worthwhile, therefore, to reexamine the available evidence and approach the problem of vasodilator activity from points of view other than those previously described.

Lewis and Pickering (4) suggested that heating the body produces maximal vasodilatation in the skin of the extremities by inhibiting vasoconstrictor impulses and also by stimulating additional active dilatation by vasodilator impulses. If this is true, local nerve block performed during pronounced heating of the body or of the other extremities should interrupt these vasodilator impulses, exclude active vasodilatation, and produce a slight but definite fall of skin temperature. The magnitude of the reduction should be proportional to the postulated activity of the vasodilator mechanism at the time of the block.

METHOD

Patients on the surgical wards of the Massachusetts General Hospital were studied. Before beginning the experiment, the patient was placed in the cold room and covered only by a loin cloth. Skin temperatures were determined by means of 8 iron-constantan thermocouples which led to an electronic, nongalvanometric, continuous balance potentiometer.¹ This recorder registered in rotation every 30 seconds so that each thermocouple registered every 4 minutes.

When skin temperatures were determined on the hand, the palmar surface of the distal phalanx of the second and fifth digits were used. The plantar surface of the distal phalanges of the toes and a point on the lateral aspect of the dorsum of the foot were used in obtaining skin temperatures of the lower extremity. The shielded wire proximal to the naked thermocouple was taped to the appropriate site at least 2.5 cm. away from the point of

actual determination so that there was no interference with heat loss at the point of determination.

Rectal temperatures, when obtained, were recorded by means of a resistance bulb and potentiometer recording on a circular chart readable to 0.02° centigrade.² The values at 5-minute intervals were charted. Procaine or metylocaine hydrochloride was used for the local blocks. The ulnar nerve was blocked at the elbow. Ankle block was achieved by combining the conventional posterior tibial block with complete ring block at the ankle. The spinal block and the ring block of the toe were performed in the conventional fashion. Care was taken to make certain that epinephrine was not added to the anesthetic agent. In those patients in whom a sympathectomy had been done, the blocks were always performed on the intact side.

Indirect vasodilatation in the hands was induced by placing the legs in warm water at 43-44° C. up to the knees (8, 9). Vasodilatation in the feet was induced by placing the arms in warm water up to the elbows. In 1 experiment, number 4, an air envelope, through which the arms and head protruded, covered the patient, and warm air at 45° C. was blown into it. In 4 cases rectal temperature was recorded. In all cases, after placing the legs or arms in warm water, the degree of perspiration was noted.

In order to control the factor of evaporation, latex rubber was sealed over the area under observation with collodion in 2 experiments, numbers 7 and 8. In this way the loss of heat occurred from a dry surface both before and after the block.

RESULTS

Figure 1 is the chart of experiment 2 and is representative of experiments 2 to 8. The patient was brought into the cool room in which the temperature was maintained at 19.7° C. He was covered only by a loin cloth. The control temperature plateau prior to heating was obtained and at 10:30 a.m. the arms were placed up to the elbows in water at 43-44° C. Sweating began at 10:40 a.m. and soon became profuse. This was continued until a second plateau was reached and at 11:44 a.m. a complete left ankle block, including the posterior tibial nerve, was performed. Just prior to the block a towel was placed over the left foot; the artificial rise in skin temperature thus induced is indicated by broken lines in Figure 1. The

¹ Brown Instrument Co., Boston, Mass.

² Foxboro Instrument Co., Foxboro, Mass.

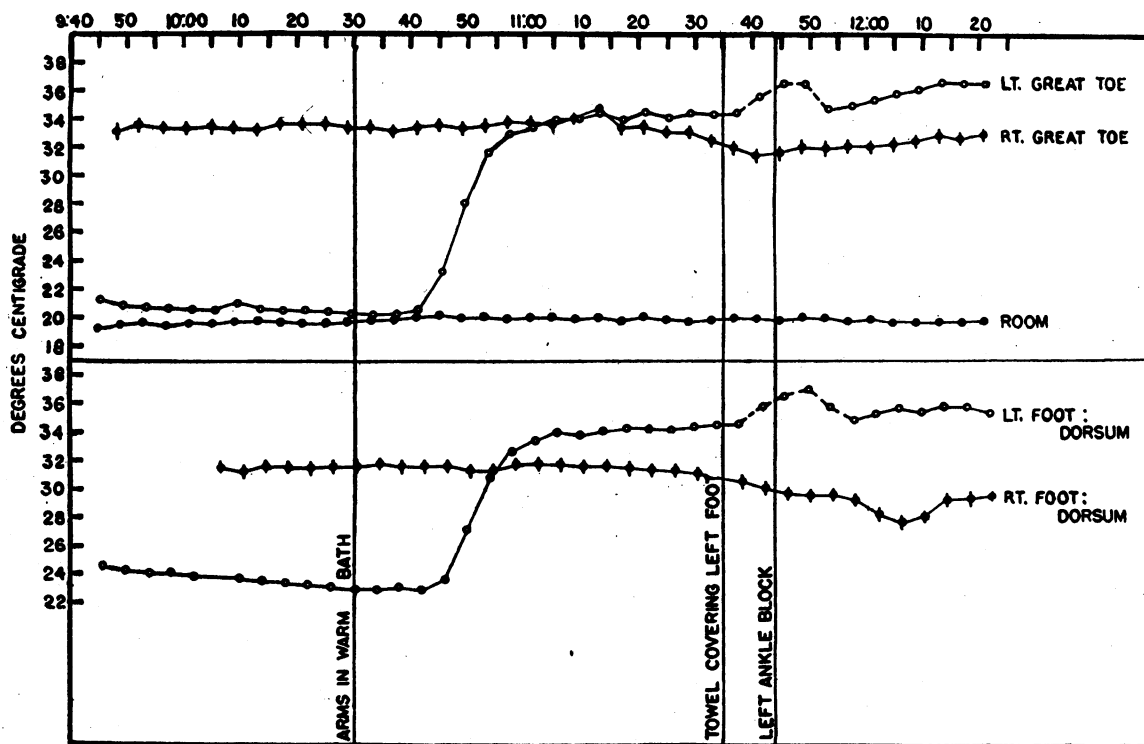


FIG. 1. PATIENT J. H., EXPERIMENT No. 2, A RIGHT LUMBAR SYMPATHECTOMY

Arms immersed in warm bath at 10:30 a.m. Towel covering left foot produced artificial rise in skin temperature indicated by dotted lines. Ten minutes after start of ankle block, anesthesia was complete and the skin temperature of the left foot and great toe rose above the pre-block level.

towel was removed immediately and anesthesia began to set in at 11:50. This was followed by a sustained rise in skin temperature that exceeded the pre-block level by 2.1° C. on the great toe and 1.4° C. on the dorsum of the foot. A full block was still in effect at the end of the experiment.

Had active vasodilator impulses been responsible for the height of skin temperature engendered by the heating of the indifferent extremities, blocking the local nerve supply should have resulted in a fall in skin temperature. A rise actually occurred. Reflex activity in the sympathectomized extremity was apparently absent.

Table I summarizes the results. Experiment 1 was essentially a reproduction of one type of procedure upon which Lewis and Pickering based their conclusions; and, although our data are similar to theirs, we believe, as do Warren *et al*, that another interpretation is tenable. This view is supported by the results of experiments 2 to 8. Experiment 2 has already been described. In experiments 2 to 8 no evidence could be found that

active vasodilators took part in the reflex vasodilatation resulting from heating the extremity or the body. Local nerve block in these experiments was followed by a rise in skin temperature instead of a fall in 5 of the 7 experiments, and in the remaining 2 the nerve block resulted in no appreciable change. In none did a fall in the skin temperature occur.

Experiments 7 and 8 represent attempts to control the factor of evaporation in order to be certain that the rise in skin temperature following the local nerve block was not due to the cessation of sweating. In these experiments the area from which the skin temperature was determined was covered with latex rubber and sealed with collodion so that heat loss occurred from a dry surface both before and after the nerve block.

Figure 2 is the chart of experiment 8. The left fifth finger was covered with a finger cot at 1 and indirect vasodilatation was induced by placing the legs in warm water at 2. Just prior to the block the patient became quite apprehensive, and

TABLE I

Response of skin temperature in normal and sympathectomized extremities to indirect vasodilatation and the response of normal extremities to indirect vasodilatation plus local nerve block

Exp. no. and patient	Disease	Room temp.	Sites of skin temperature determination	Type of block*	Skin temperature					Rise in rectal temp.
					Intact side			Sympathect. side		
					Before heating	During heating	After heating and block	Before heating	During heating	
1. J. H.	Vasospasm	°C. 18.5	Great toe	None	°C. 19.2	°C. 35.8	°C.	°C. 33.2	°C. 32.3	°C. N
			Dorsum of foot	None	21.2	35.4		32.0	31.4	
2. J. H.	Vasospasm	19.7	Great toe	P. tibial and compl. ankle	20.3	34.5	36.6	33.4	31.6	N
			Dorsum of foot		23.0	34.5	35.9	32.8	31.2	
3. E. C.	Post-polio vascular disorder	21.5	Great toe	None				34.5	34.3	2.3
			Second toe	Ring block second toe	24.5	33.7	36.0			
4. A. B.	Normal	20.0	L. 5 finger	Ulnar n. at elbow	21.3	35.7	36.1			N
			R. 5 finger	None	21.3	34.6	34.8			
5. A. B.	Normal	32.0	L. 5 finger	None		35.4	36.0			N
			R. 5 finger	R. ulnar n. at elbow		34.4	36.2			
6. P. Z.	Raynaud's	22.0	2 finger	None	23.4	32.7	33.3	29.6	27.2	0.3
			5 finger	Ulnar n. at elbow	23.1	32.8	32.9	24.5	26.2	
7. G. C.	Buerger's	20.0	R. foot dorsum	Spinal to D3	24.8	32.9†	32.9†			1.1
			L. 3 toe	Spinal to D3	22.3	24.3	25.3			
8. K. M.	Raynaud's	19.0	L. 5 finger	L. ulnar n. at elbow	20.4	32.8†	34.0†			0.7
			L. 2 finger	None	20.0	32.1	32.0			
9. A. B.	Normal	20.4	R. 5 finger	R. ulnar n. at elbow	22.1	34.3				N
			L. 5 finger	None	22.6	22.2				

* Block always performed on intact side.
 † Area covered with rubber and sealed.
 N Not recorded.

a slight fall in skin temperature occurred. After the block, however, the unblocked area (the left second finger) resumed its previous level, while the blocked area exceeded its pre-block level by 1.2° C., even though the factor of evaporation was controlled throughout.

Figure 3 is the chart of experiment 7. Indirect vasodilatation was begun at 1. The dorsum of the foot was covered by latex rubber and sealed at the arrow. Spinal anesthesia was induced at 2. The arms were removed from the warm bath at 3. Despite the fact that the arterial pressure fell and

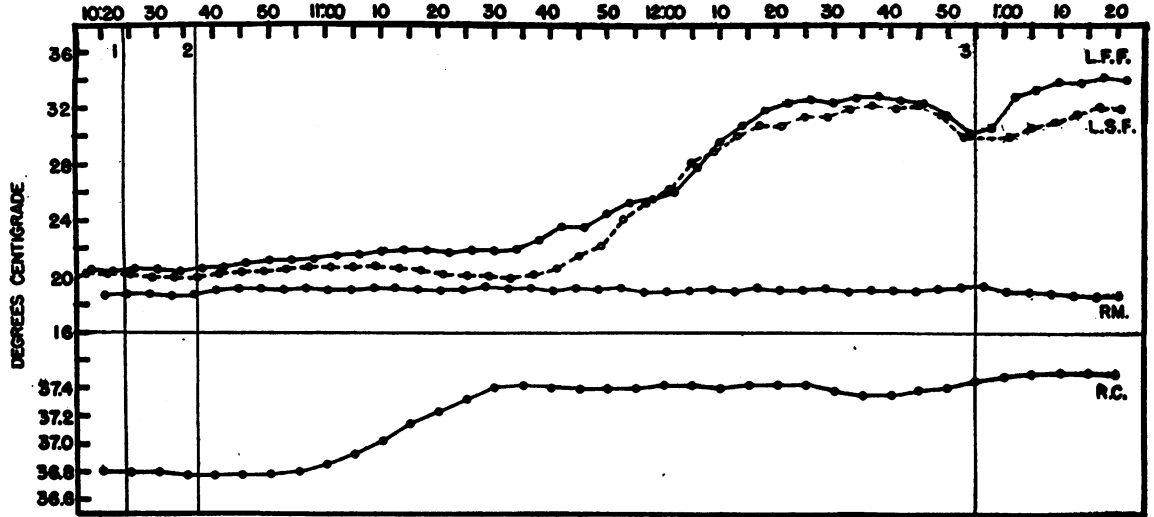


FIG. 2. PATIENT K. M., EXPERIMENT No. 8

L.F.F.—Left fifth finger (unbroken line). L.S.F.—Left second finger (broken line). 1—Left fifth finger covered with finger cot. 2—Legs immersed in warm water. 3—Procaine block of left ulnar nerve at the elbow. Patient became quite apprehensive just prior to the block, accounting for the fall in skin temperature. Following the block the anesthetized area rose to 1.2° C. above its pre-block level. The unanesthetized area resumed its previous level.

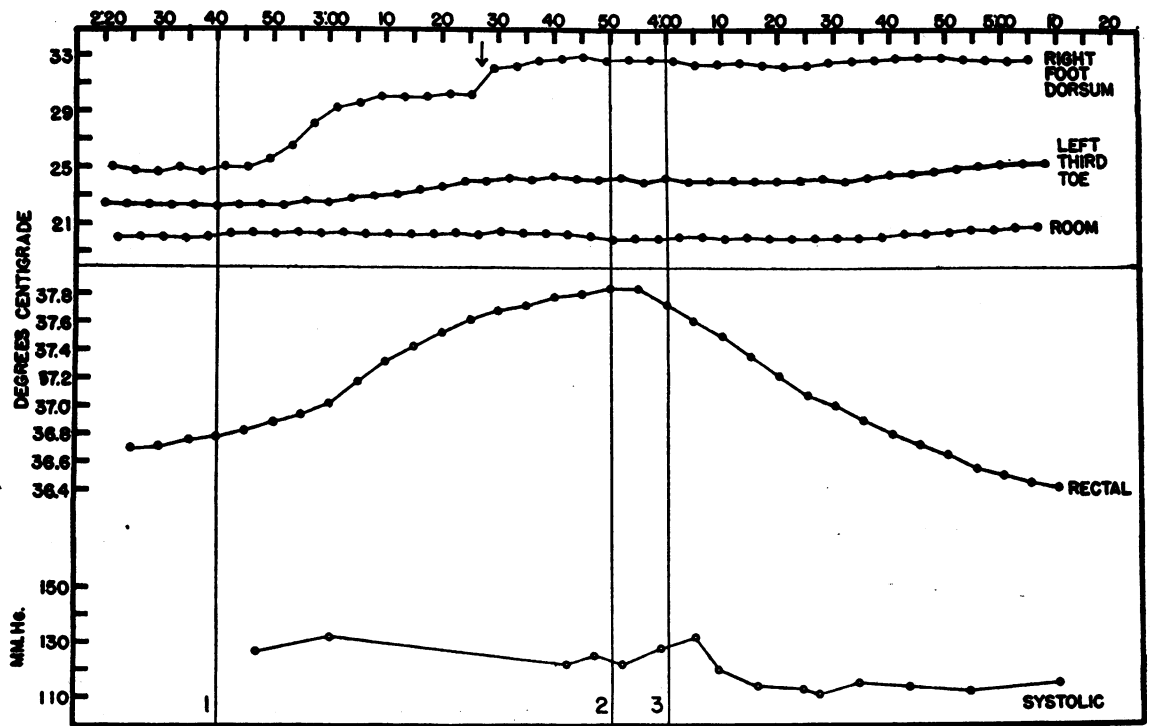


FIG. 3. PATIENT G. C., EXPERIMENT No. 7

1—Arms immersed in warm water. Arrow—right foot covered with latex rubber and collodion seal. 2—Full spinal block to D3. 3—Arms out of warm water. Despite a 1.4° C. fall in body temperature and a lower systolic arterial pressure, the skin temperature of the right foot maintained its previous level. (See text.)

there was a 1.4° C. fall in body temperature, the skin temperature of the blocked area did not fall, but maintained its pre-block level. In this experiment, as in experiment 8, the factor of evaporation was controlled by making certain that heat loss from the area occurred from a dry surface both before and after the block.

In experiments 2 to 8 inclusive (illustrated by Figures 1 to 3), "maximal vasodilatation" was first induced by heating the indifferent extremities with warm water or by heating the body with warm air. Heating was intense enough (a) to produce profuse sweating in every instance and (b) to elevate rectal temperature 0.3° to 2.3° C. in the 4 experiments in which it was determined. If vasodilator nerves share in the control of blood flow to the skin of the digits, there is every reason to believe that the stimulus used in these experiments was adequate to bring them into action. Subsequent local nerve block resulted in complete anesthesia in the appropriate area and a fall in skin temperature did not occur in any case. It is reasonable to conclude from these results that the vasodilatation produced by pronounced body warming does not include any measurable component that can be attributed to vasodilator impulses.

DISCUSSION

It is well to point out that small changes in skin temperature at the higher ranges (33° to 36° C.) reflect relatively major alterations in blood flow. Wright and Phelps (10) have found that a rise of 1° C. in this range may represent a change in the corresponding blood flow determination from 3 ml. per 100 ml. of tissue per minute to a value of 10 ml. per 100 ml. of tissue per minute.

In recent years, support for the theory that vasodilator fibers exist in the skin of the extremities comes mainly from 4 groups of investigators. Lewis and Pickering (4) performed experiments in which normal subjects and sympathectomized patients with Raynaud's disease were studied. They showed that in an individual who had undergone a dorsal sympathectomy, the temperature of the fingers of the intact hand rose to higher levels after indirect vasodilatation than did those of the sympathectomized side. They concluded from this that it was the presence of vasodilator fibers on the undisturbed side that was responsible for the higher level of skin temperature attained. Ex-

periments were also done in which an ulnar nerve block was performed on a patient with Raynaud's disease while the patient was in a cold room. Indirect vasodilatation was then induced, and it was observed that the skin temperature of the anesthetized area did not rise while that of other areas did rise. Similar observations were made on both the lower and upper extremities (1, 2).

Grant and Holling (3) subjected patients to body heating and studied its effect on blood flow in the forearm. They concluded that the increase in flow depended upon the integrity of the sympathetic nerves and that vasodilatation was brought about both by inhibition of vasoconstrictor tone and by active vasodilator impulses. In their observations, a forearm was flushed and warmed directly and then kept so by indirect heating. Local nerve block then caused the anesthetized area to pale, cool, and cease sweating. However, as pointed out by Warren, *et al* (6), the authors are unable to account for the difference between the effect of sympathectomy which increases forearm flow and the effect of local nerve block which, they concluded, under certain conditions, diminishes it. It should also be added that these investigators added epinephrine to the procaine with which the local nerve blocks were performed. Similar experiments were performed by Doupe *et al* (11).

Warren *et al* (6) also point out that when body heating produces indirect vasodilatation which is greater in the intact than in the sympathectomized extremity, this cannot be used as evidence for the presence of vasodilator fibers, for it has been repeatedly demonstrated that the peripheral vascular bed of a sympathectomized extremity acquires an appreciable tone and that this tone is not affected by efforts at homeostasis mediated through the central nervous system. We have in fact observed several individuals in whom a unilateral sympathectomy had been performed and in whom a "paradoxical response" was observed, that is, when indirect vasodilatation was induced, the temperature of the sympathectomized extremity fell several degrees while that of the intact side responded in the usual fashion. This phenomenon, produced experimentally, is accompanied by a slight lowering of the arterial pressure.

Warren *et al* (6) have demonstrated that complete procainization of the sympathetic supply to the upper extremity causes an increase in blood

flow that is equivalent to the maximal increase produced by immersing the hand in water at 43° C. plus indirect heating. The authors concluded that these data make it unnecessary to assume the presence of active vasodilator fibers to the skin.

In the various investigations which purport to demonstrate the functional activity of vasodilator fibers, the lack of a rise in skin temperature following local or paravertebral block plus indirect heating was construed as being due to a lack of vasodilator activity in the anesthetized area. These experiments were made on patients suffering from vasospastic disease. Yet we know that where diminished peripheral flow is due to arteriolar constriction alone, block of the nerve supply to that area is followed by a local rise in skin temperature.

In this connection it is profitable to examine the chart of patient number 7 (Figure 3). At point 1, the arms were placed in warm water and the skin temperature on the dorsum of the right foot rose while that of the left third toe did not. Had a procaine block of the left third toe been performed prior to 1, this curve would resemble that type of chart upon which the main body of evidence in favor of vasodilator fibers in the human skin is founded. That the block was not performed indicates that other factors may contribute to this type of result. Support is given this view by the fact that this result has not been obtained in the normal human, but only in the patient with well established peripheral vascular disease. It is of additional interest to note that 8 days after a left lumbar sympathectomy, the skin temperature of the left third toe was 30.4° C. after the patient had been exposed for 1 hour in the cold room.

It cannot be denied that, prior to the block, when the skin temperature is high due to indirect heating, there may remain a certain amount of vasoconstrictor plus vasodilator tone, if such exists. In this case, the release of the residual vasoconstrictor tone may overbalance the release of vasodilator tone resulting in a net rise in skin temperature. It is for this reason that we have not found it possible to devise a conclusive experiment which would demonstrate that vasodilator fibers to the human skin do not exist. It was believed, however, that the above experiments do

strongly suggest 2 facts: first, that previous investigations have not established the functional activity of vasodilator fibers in the hand or foot; second, that, if they do exist, their functional significance is very limited.

It is not the purpose of this report to consider the controversy as to whether or not active vasodilator impulses travel in posterior root fibers. After careful study, Westbrook and Tower (2) concluded, "The concept that nerve fibers emerge from the spinal cord into the posterior roots in adult mammals including man is without foundation in anatomical fact or physiological necessity and therefore may be dispensed with." Whether this point of view becomes generally recognized as correct is not important to the issue involved in this study. The nerve blocks performed in these experiments were either subarachnoid or peripheral somatic and therefore should block all impulses going to the area under examination whether they travel via the somatic or autonomic pathways.

Additional evidence indicating that active vasodilator fibers traveling in somatic nerves are of little or no importance in elevating the skin temperature consequent to indirect vasodilatation may be seen in Figure 1. The right lumbar sympathectomy had interrupted the sympathetic pathways supplying this patient's right lower limb. The absence of any reflex change in that extremity is evidence that the remaining nerves supplying that extremity were inactive in this regard. The same considerations apply to experiments 1, 3, and 6. Curves of this type are commonly seen in the literature on peripheral vascular disease (2, 4, 5). Further evidence supporting this view may be found in the work of Dole and Morison (13).

These considerations have clinical as well as physiological implications. Grimson, in a recent, extensive review on the limitations of sympathectomy as a therapeutic procedure (7), cites the possibility that the removal of vasodilator fibers may account for the lack of benefit in some instances. We believe that in the normal human, as well as in the patient with well established Raynaud's or Buerger's disease, vasodilator fibers are of only slight significance at most. This factor, therefore, should not be allowed to enter into the consideration of whether sympathectomy should

be performed in any given case, insofar as the circulation to the skin of the hands and feet is concerned.

SUMMARY

Experiments have been performed to test the theory which holds that vasodilatation in human skin in response to the heating of the indifferent extremities is due in part to vasodilator impulses. It was found that at the height of the elevation of skin temperature due to reflex vasodilatation, block of the nerve supply to that area did not cause a fall in skin temperature. In most cases an elevation occurred. These observations were made upon patients with a normal peripheral vascular bed as well as in patients with Raynaud's and Buerger's disease.

It may be concluded that if active vasodilator fibers exist in the skin of the digits their functional significance is very limited. The indirect vasodilatation produced by heating the indifferent extremities is, therefore, due to the central inhibition of vasoconstrictor impulses. Evidence was cited to indicate that these considerations apply to both somatic and autonomic pathways.

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