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Studies on Antidromic Vasodilatation. II. Synaptic Connections in the Dorsal Root Ganglion.*†

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Neuroanatomy and histology textbooks discuss, if only briefly, those synapses described by Dogiel which are to be found in the dorsal root ganglion. However, the further connections of these synapses are, as yet, obscure.

Hasama[1] painted .2% nicotine on the dorsal root ganglia in the toad and was then unable to obtain the vasodilatation previously elicited by stimulation of the peripheral stump of these roots sectioned between the ganglion and the cord. An intravenous injection of 1% nicotine tartrate was found by Kuré *et al.* to prevent vasodilatation produced by the stimulation of the peripheral stumps of the lumbar and sacral dorsal roots sectioned between the ganglion and the cord in dogs.[2] These workers concluded that para-sympathetic efferent fibers synapse in the dorsal root ganglia. Ranson[3] and Ranson and Wightman[4] have shown that reflexly induced vasodilatation is definitely prevented by intravenous administration of nicotine in dogs and that the reflex pathway concerned in this response does synapse in the dorsal root ganglia. Sheehan,[5] in a recent review, expresses the opinion that the preponderance of evidence indicates that dorsal root synapses do occur.

Wybauw[6] found that a 1% solution of nicotine tartrate injected into the dorsal root in dogs failed to abolish the effects of antidromic vasodilatation. Much earlier, Bayliss[7] had noted that when nicotine was painted on the dorsal root ganglion, one could still obtain the characteristic vasodilatation. Such facts led these two observers to conclude that no synapses which were concerned with the vasodilatation phenomenon existed in the dorsal root ganglia.

Obviously direct injection of nicotine into the dorsal root ganglion would produce the best conditions for inhibiting synaptic transmission. Wybauw's method was therefore used on frogs because it was felt that direct observance of arteriolar dilatation, as in the web of the frog's foot, would be a more sensitive way of determining such changes than was Wybauw's use of temperature changes in the paw of the dog's foot.

Method. The frog *Rana pipiens* was used. Under urethane, or after decerebration, the lumbar region of the cord was exposed. In this region the eighth dorsal root and its ganglion can be freely disclosed. A long section of this root is easily obtained if it is severed at its exit from the spinal cord and traced down intraspinally to the ganglion just outside the spinal column. The web of the corresponding foot was so arranged on a piece of cork that it could be observed directly with a microscope under low power. The blood vessels were easily visible and their widths measured by an ocular micrometer. The distal stump of the dorsal root, cut central to the ganglion, was stimulated at its proximal end or in the small portion peripheral to the ganglion with a thyratron stimulator. Leakage of current from the dorsal root into the

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1 Hasama, B. I., *Arch. Int. d. Pharm.*, 1931, **41**, 145.

2 Kuré, K., Saito, S., and Okinaka, S., *Arch. f. d. ges. Physiol.*, 1936, **238**, 290.

3 Ranson, S. W., *Am. J. Physiol.*, 1922, **62**, 383.

4 Ranson, S. W., and Wightman, W. D., *Am. J. Physiol.*, 1922, **62**, 392.

5 Sheehan, D., *Yale J. Biol. and Med.*, 1934, **7**, 425.

6 Wybauw, Lucien, C. R. d. Soc. d. Biol., 1936, **121**, 1377.

7 Bayliss, W. M., *J. Physiol.*, 1900, **26**, 173.

TABLE I.

Tabulation of data indicating changes in the diameters of various blood vessels in the web of the foot of the frog following electrical stimulation of the peripheral end of the cut dorsal root by a thyratron stimulator and the Harvard inductorium before and after injection of the dorsal root ganglion with .25 cc 1% nicotine. The eighth dorsal root in a different specimen of *Rana pipiens* was used in each case. Weak current strengths were used for each stimulation. In the case of the thyratron stimulator, these stimuli were applied at the rate of 2 per second whereas in the case of the Harvard inductorium tetanic stimuli were used.

Vessel	Diameter (μ) before stimulation		Increase in diameter (μ) during stimulation		Stimulator used: Thyratron (T); inductorium (I)
	Without nicotine	With nicotine	Without nicotine	With nicotine	
Large artery	195	—	0	—	I
Small artery	75	—	45	—	I
" "	75	75	15	0	I
" "	60	45	18	0	I
" "	60	45	30	0	I
" "	60	60	11	15	I
" "	60	60	18	0	I
" "	75	75	8	0	I
" "	45	15	15	0	I
" "	75	60	45	0	I
" "	90	90	23	15	T
" "	120	113	45	0	T
" "	105	105	45	0	T
Arteriole	60	60	30	0	I
"	30	30	15	0	I
"	75	60	18	15	I
"	60	45	15	0	I
"	60	60	22	0	T
"	30	15	23	0	T
"	60	—	15	—	T
"	45	—	15	—	T
"	30	—	15	—	T
"	30	15	30	15	T
"	45	45	30	15	T
"	45	45	15	0	T
"	90	90	60	0	T
"	45	45	15	0	T
"	45	45	45	0	T
"	45	45	30	0	T
"	45	45	15	0	T
"	45	60	30	15	T
"	30	30	15	0	T
"	60	60	30	0	T
"	45	45	15	0	T
"	30	60	15	15	T
Vein	60	60	0	0	I

dorsal root ganglion was minimized by employing weak currents produced at a slow rate (the type best for production of parasympathetic-like responses) and by using a sufficiently long piece of dorsal root central to the ganglion. The frog rested on a metal plate which formed the indifferent electrode, whereas the stigmatic electrode consisted of a platinum wire sealed in a small glass tube. This tube was fixed in position near the open cord and the peripheral end of the cut dorsal root was made to adhere to the bit of platinum exposed at the end of this tube. The vasodilatation produced by stimulation of the root central and peripheral to the ganglion was then noted and recorded. This stimulation was performed again in the same manner after the direct injection of .25 cc of 1% pure nicotine into the ganglion and the resultant effects again noted. The changes in width of the observed blood vessel were taken as the criteria for the extent of peripheral vasodilatation.

Results. As shown in Table I, the injection

of nicotine into the dorsal root ganglia of frogs caused complete suppression of the previously elicited vasodilatation. Whereas the average increase in the diameter of small arteries as a result of stimulation of the peripheral stump of the sectioned dorsal root had amounted to 21 μ, it was reduced to O following nicotine injection in 11 out of 13 cases. Similarly, in 17 out of 22 cases of arteriolar dilatation where the average increase in width amounted to 23 μ, there was no change in diameter after nicotine injection into the dorsal root ganglion. Control experiments indicated that the blocking effect of nicotine injection was not due to the pressure of the fluid since injections of .25 cc of 1% atropine sulfate into the ganglion failed to prevent the vasodilator response.

It was further found that during an interval of 2 minutes continuous stimulation of the un-nicotinized dorsal root, the flow of blood in some (5) cases was found to be reduced in the capillaries to 70% of its original rate (number of RBCs per 10 seconds).

To complete the experiment an attempt was made to show that vasodilatation elicited from this portion of the root, peripheral to the ganglion, could still be obtained. In some cases stimulation of the dorsal root peripheral to the nicotinized dorsal root ganglion caused vasodilatation. However, this was usually associated with simultaneous muscular twitching which probably resulted from current leakage to the corresponding ventral root from the very short piece of dorsal root available for stimulation.

Discussion. The results presented in Table I indicate that vasodilatation caused by stimulation of the peripheral end of a dorsal root sectioned between the ganglion and the cord was prevented by the injection of nicotine into the dorsal root ganglion. These results contradict those obtained on dogs by Wybauw. The method of direct injection into the ganglion as described here and as used by Wybauw would seem to be preferable to painting the ganglion (Hasama, Bayliss) or intravenous injection (Kuré) since the nicotine effect would be more localized. The possibility that nicotine may block fine nerve fibers is not excluded since this factor was not controlled. It is a well known fact, however, that nicotine seems to act specifically on synaptic connections so that impulse transmission across the synapse is prevented. The experiments described here provide further definite proof that a synapse is interposed between the vasodilator fibers central to the ganglion and those peripheral to the ganglion. It has been shown previously by Bach[8] that anatomically efferent fibers emerge from the cord and pass peripherally in the dorsal roots. The experiments described here show that physiologically efferent fibers synapse in the dorsal root ganglion. There is no evidence to indicate that the anatomically and physiologically efferent fibers are the same. However, the possibility exists that these fibers are identical and synapse in the dorsal root ganglion.

Conclusions. Evidence is presented to show that synapses exist between physiologically efferent fibers which course the dorsal root in the frog and that these synapses are present in the dorsal root ganglia.

It is further concluded that these synapses are concerned in the transmission of the impulses which result in peripheral vasodilatation since injections of nicotine into the dorsal root ganglia prevent the appearance of vasodilatation which occurs following stimulation of the peripheral stump of the dorsal root sectioned between the ganglion and the cord.

[8] Bach, L. M. N., to be published.