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Remote Electrodermic Response to an Algogenic Stimulus. Pathway and Spinal Integration

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The pathway of a non-segmental sudomotor reflex was studied in rabbits (New Zealand white). By means of thermic stimulation (45° during 30") at the lateral border of the foot, a sudoral response was evoked in a circumscribed area of the pinna. By sequential sections of different nerves and the nervous network around the saphenous and femoral vessels, it was possible to establish the following afferent pathways to the spinal cord: lateral plantar nerve, tibial nerve up to the tuber calcanei, saphenous perivascular network, femoral perivascular network and femoral nerve. The fibres responsible for the podo-auricular sudomotor reflex penetrate into the spinal cord above L4, because the spinal transection at this level does not alter the auricular response. Since the hemisection of the spinal cord at T6 suppresses this reflex in the pinna of the same side, it must be concluded that the spinal pathway is ipsilateral. The efferent pathway abandons the spinal cord beneath segment C6: in fact, the spinal transection at C6 does not alter the auricular response to plantar stimulation. Finally, the sudomotor impulses reach the pinna sweat glands with the auricular vessels.

Key words: Electrodermic response, Algogenic stimulus, Podoauricular reflex.

It is well known in clinical studies that the pinna increases cutaneous perspiration as a result of a painful stimulus in different somatic areas (3, 11, 19, 23, 25, 27, 31). In addition, several authors have established an auricular somatotopy (7, 12, 13, 20, 21, 30) i.e., the algogenous stimulus reactive zone of the pinna is constant and located in the same area. The effector part of this sudomotor reflex is autonomous in nature and, concretely, sympathetic (15, 16, 28, 29); and the afferent one is somatic or autonomous, depending upon the organ in which the stimulus originates.

The pathway of a segmental reflex is light to follow but that of a non segmental one, such as the podo-auricular sudomotor reflex is, surely, more difficult.

In the revised bibliography we did no find studies on this particular and therefore we have considered interesting to investigate the neuroanatomical basis of this reflex, in the rabbit.

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Materials and Methods

The experimental animal used was the New Zealand albino rabbit; 50 adults and 12 of 500-700 g b.w. The algogenous stimulus (thermic in nature) consisted in the application of a Zener diode to the shaved skin of the lateral border of the foot at 45° C for 30 s. The electrodermic resistance was determined by means of a puntoscope (sedatelec) that measures the cutaneous resistance to the passage of a 3 mA, current, integrating the percentage difference of the resistance present at both terminals. If the resistance registered by the central electrode is at least 1/18 that registered by the peripheral electrode, the puntoscope emits a sonorous signal. These experiments were carried out in a room with no noise, at the same hour of the day, with the animal hanging comfortably in a hammock, blindfolded.

All of the lateral face of the pinna was investigated; and in the successive explorations the beginning and direction of these explorations were different in order to avoid a possible conditioned response. In all cases, the explorations were performed before and after surgery. The first exploration, previous to surgery, allowed us to know the pinna's positive points in the absence of stress. The second one was carried out after the thermic stimulation and showed the auricular positive points corresponding to the algogenic area. The explorations after surgery were performed on days 2 and 5. In all cases both pinnas were examined and the algogenous stimulus was applied to both feet successively.

All the experimental groups consisted of 5 rabbits, except those with spinal cord transection or hemisection (3 animals), and those with WGA-HRP deposit (10 rabbits).

The experimental groups were the following: 1) Section of the schiadic nerve at the distal border of the gluteal region; 2) subinguinal section of the femoral nerve; 3) section of the cutaneous branch of the femoral nerve at the knee; 4) section of the femoral vessels at the knee; 5) section of the tibial nerve at the tuber calcanei; 6) section of the tibial nerve at its entry to the gastrocnemius muscle; 7) section of the saphenous vessels at the tuber calcanei; 8) section of the saphenous vessels at the distal part of the muscular belly of the flexor digitorum longus; 9) transection of the spinal cord at segment L3; 10) the same at T6; 11) the same at C6; 12) hemisection of the spinal cord at T6; 13) WGA-HRP deposit at the proximal end of the femoral nerve cut at a sprainguinal level; and, 14) section of the deep posterior branch of the auriculocaudal artery.

The surgery was performed under nembutal anesthesia (32 mg/kg i.p.) with the surgical techniques appropriate to each experiment and with the help of a dissecting microscope. The explorations concluded, the rabbits were sacrificed under deep anesthesia and at necropsy the corretness of the surgery was verified.

For the experiment of retrograde labeling with WGA-HRP, the rabbits selected were younger (500-700 gm). Thirty mg of a 1% solution of WGA-HRP was introduced into a polyethylene tube with one of its ends closed with silicone; and the proximal stump of the cut femoral nerve was introduced into the other end. The tube was secured to the adjacent muscle by one stitch, and the free end of the tube was sealed with silicone. The animals were allowed to recover for 72 hours, after which they were deeply anesthetized and perfused transcardially. The blood was removed by a brief wash with saline followed by 1 l of 1% paraformaldehyde and 1.25% glutaraldehyde in 0.1 M phosphate buffer at pH 7.4, at room temperature. The perfusion was ended by passing 2 l of fixative at 4°C followed by 1 l of 10% sucrose in phosphate buffer, also at 4°C, while the animal's head was covered with crushed ice.

The spinal cord and the spinal ganglia comprised between T11 and L5 were removed and left overnight in 30% sucrose in phosphate buffer. The different pieces were cut transversally in a freezing microtom at 50 μm. Every fifth section of the spinal cord and every section of the spinal ganglia were reacted. All the series were mounted onto gelatinized slides, left to dry in the air and reacted according to MESULAM's protocol (17, 18). Sections were dehydrated, converslipped and analyzed under both dark- and bright-field optics. Drawings were made by means of a camera lucida attached to the microscope and the labeling plotted onto the drawings. Laminar boundaries in the spinal cord were defined after Rexed with the help of adjacent sections stained with cresyl violet.

Results

Considering the large number of experimental groups, it seems convenient to summarize the results by dividing them into two groups: those that caused an abolition of the auriculo sudomotor reflex, and those that did not alter this effect. In the discussion, however, we will make the opportune observations to arrive at a correct interpretation of these results. The sudomotor reflex was not affected after the following sections: the ischiadic nerve, femoral nerve at the knee, saphenous vessels at the tuber calcanei, tibial nerve at the entry into gastrocnemius, transection of the spinal

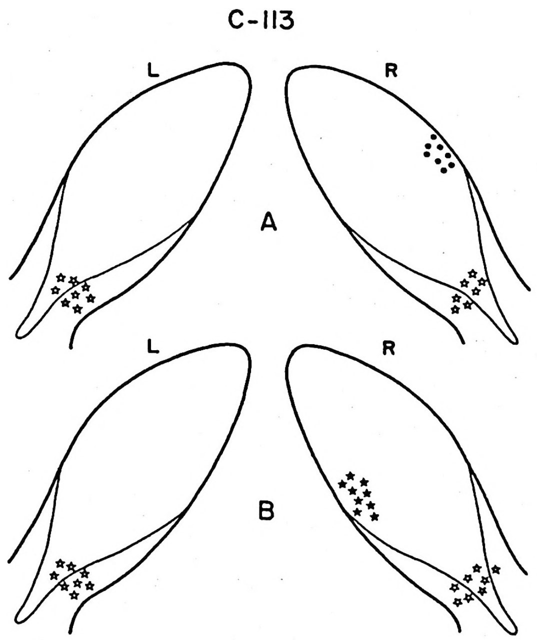

Fig. 1. *Representation of the lateral surface of the pinna, right (R) and left (L).*
A) ⁂ Basal positive points. ● Positive points after stimulation of the lateral palmar border. B) ⁂ Basal positive points. ★ Positive points after stimulation of the lateral plantar border.

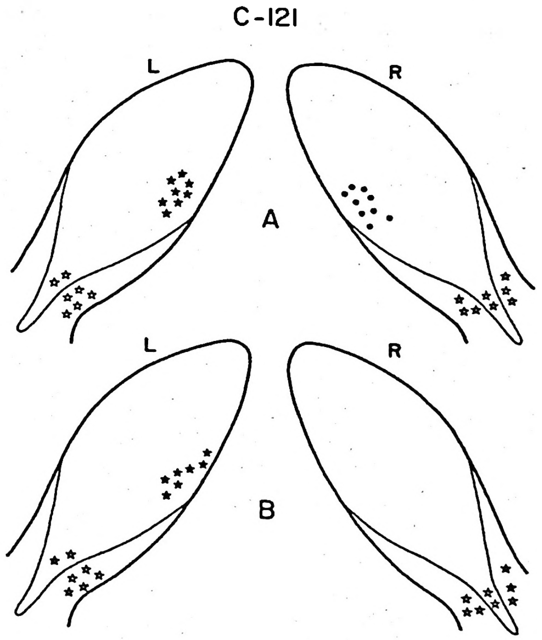

Fig. 2. *Lateral surface of the pinna.*
A) ⁂ Basal positive points. ★ Positive points following the stimulation of the lateral plantar border (left). ● Positive points following the stimulation of the lateral plantar border (right). B) Schema showing the absence of the corresponding positive points following lateral plantar border stimulation in the rats with section of the femoral nerve.

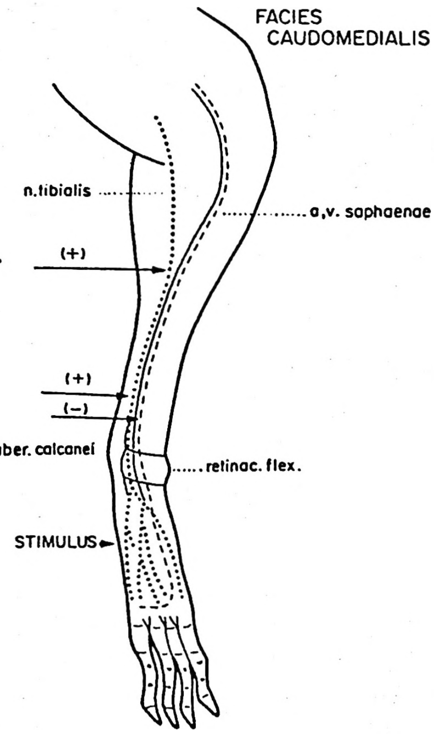

Fig. 3. *Representation of the distal region of the left caudal extremity, showing (arrows) the points where the section were performed and the effect positive (+) or negative (−) on the auriculosudomotor effect.*

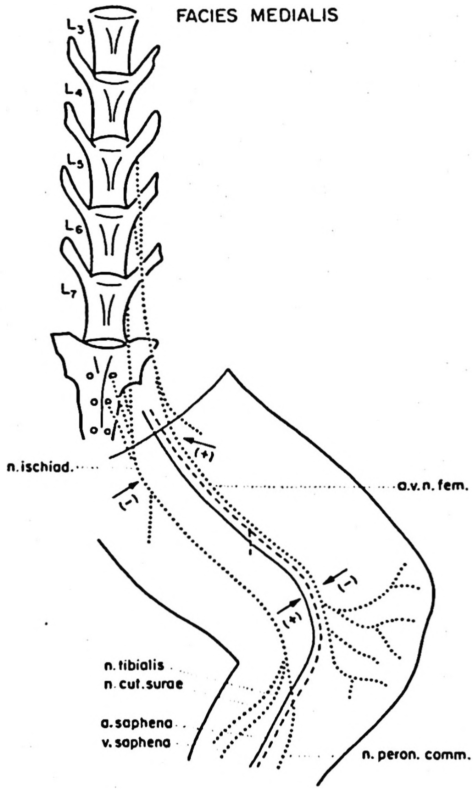

Fig. 4. *Proximal region of the caudal extremity.* Same indication as in fig. 3.

cord at L3 and C6 segments. The following experiments, on the contrary, suppressed the auriculo-sudomotor reflex ipsilaterally: 1. the section of the femoral nerve at the inguinal region; 2. of the femoral vessels at the knee; 3. of the saphenous vessels at the caudal end of the muscular belly of the flexor digitorum longus; 4. of the tibial nerve at the tuber calcanei and, 5. the transection of the spinal cord at T6; finally, 6. the section of the deep posterior branch of the auriculo-caudal artery (fig. 1-5). The study of the spinal afferences proceeding from the femoral nerve by means of the retrograde transport of the WGA-HRP has shown that, although this nerve reaches the spinal cord through the spinal nerves L4 and L5, their fibres run up to the spinal ganglion T11. The ganglion which showed a larger number of labeled neurons was L5, differing slightly from L4. In the more cranial ganglia this number decreased noticeably. Spinal transganglionic labeling was observed at segments L4, L3 and L2. The labeled fibres as well as that of the labeled motoneurons of the ventral horn was sparse, obviously lower than that corresponding to the deposit of HRP in the sectioned trunk of the femoral

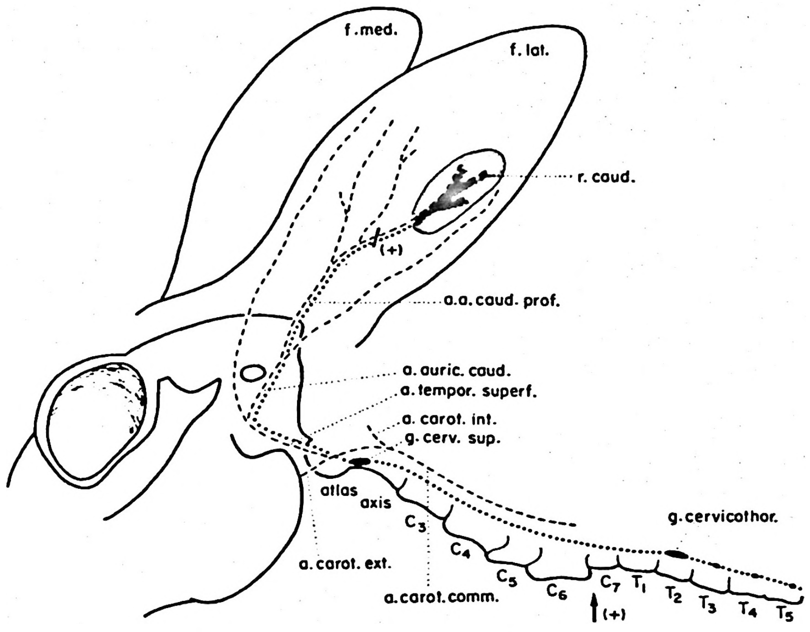

Fig. 5. *Representation of the cephalic region of the rabbit, showing the innervation and arterial supply of the pinna.*
The section of the a. caudalis profunda was followed by abolition of the positive points that normaly appear after stimulation of the left lateral plantar border.

nerve. The same experiment carried out in the rat showed a larger number of labeled fibres and motoneurons.

Summarizing these results, it is possible to sketch the pathway of the podo-auricular sudomotor reflex as follows: the thermic stimulus applied to the lateral border of the foot excites fibres of the plantar branch of the tibial nerve. These fibres run with the tibial nerve up to the tuber calcanei, where they pass into a perivascular nervous network of the saphenous vessels. At the knee level, the investigated fibres pass into the nervous perivascular plexus of the femoral vessels. At the inguinal level, these fibres run with the femoral nerve and with them reach the spinal cord. However, the spinal ganglia and the spinal segments where the sudomotor fibres are found are more cranial than those fibres corresponding to the other cutaneous sensibilities of the lateral border of the foot.

The spinal pathway is ipsilateral and the efferent limb of this reflex leaves the spinal cord below the C6 segment. Finally, the fibres destinated to the sweat glands of the pinna reach their effector organ in company of the vessels that irrigate this territory.

Discussion

Afferent pathway. — The first experiment performed to demonstrate the afferent limb of the podo-auricular sudomotor reflex was the sectioning of the ischiadic nerve at the gluteal region. The reason was clear: since the cutaneous area in which the thermic stimulus was applied belonged to the ischiadic nerve, logically, the section of this should abolish the sudomotor reflex. Surprisingly, the reflex remained unaffected. Therefore, the second experiment was the section of the femoral nerve at the inguinal region, since this was the other possible alternative of the provoked impulses to reach the spinal cord. In this case, the result was positive: the section of the femoral nerve suppressed the podo-auricular reflex. The following step was directed to find where the fibres which run with the lateral plantar nerve enter the femoral nerve. Hence, this last nerve (cutaneous branch) was cut at the knee level; however, this operation did not abolish the sudomotor reflex. This result showed that the fibres responsible for that reflex had not yet reached the femoral nerve. Considering that the femoral nerve and the femoral vessels run parallel and that around the vessels there is a neuronal network, the femoral vessels were cut together with the perivascular neural plexus at the knee level. The result was the suppression of the podo-auricular sudomotor reflex. Searching downwards to the point where the fibres abandon the tibial nerve, we cut this nerve at the level of the tuber calcanei. In this case, the section caused the abolition of the studied reflex. After that, the course between tuber calcanei and knee, remained to be known. The following experiment consisted in the section of the tibial nerve at its entry into the gastrocnemius muscle. This operation did not alter the sudomotor response of the pinna, thus indicating that the studied fibres leave the tibial nerve at a more distal point. However, cutting the saphenous vessels close to the distal part of the muscular belly of the flexor digitorum longus provoked the suppression of such a reflex. On the other hand, the section of the saphenous vessels at a point 1 cm proximal to the tuber calcanei did not have this effect.

These sequential experiments have clearly demonstrated the pathway followed by the fibres responsible for the auriculo-sudomotor reflex elicited by thermic stimulation of the lateral border of the foot. But before entering the discussion about the spinal pathway, the behavior of these fibres with respect to the spinal ganglia should be commented upon. The spinal nerves which form the femoral nerve are L4 and L5 and, consequently, a larger number of labeled neurons appeared in the spinal ganglia L4 and L5 (a mean of 472 and 365, respectively). However, labeled neurons appeared also in ganglia L3 (120) and, in decreasing number, up to the T11. Since the spinal transection at L3 did not abolish the podo-auricular sudomotor reflex, it can be concluded that the fibres responsible for this reflex penetrate into the spinal cord at a more cranial level than the other cutaneous fibres. This is, in part, confirmed by the transganglionic labeling. The number of labeled fibres in the dorsal horn and the number of labeled neurons in the anterior horn were clearly scarcer than expected in the case of the femoral nerve. This result led us to modify the exposure of the nerve to the action of the WGA-HRP, the amount and proportion of the perfusion liquids, the age of animals, etc., but the results were nearly the same. A similar experiment was carried out in rats, animals in which the transganglionic labeling was more intense and the number of labeled motoneurons was also considerably larger than in rabbits. Since the transganglionic labeling in the rabbit was most intense in L2, L3 and L4 and the labeled fibres were of a rather thin diameter, it is to be assumed that there was a selective labeling of a $A\delta$ and C fibres.

Spinal pathway. — The spinal course of this pathway is also peculiar. Though the stimulus which evoked the sudomotor reflex was algogenous in nature, its spinal pathway does not correspond to the spinothalamic tract: it is ipsilateral and the effector pathway leaves the spinal cord below the C6 level. Our experiments do not exclude the participation of supraspinal centres in this reflex (2, 4-6, 8, 10, 22, 26); however, they show that they are not indispensable, since the transection of the spinal cord at C6 did not suppress the auricular response. Therefore, we come to the conclusion that the integration of the podosudomotor reflex is spinal (1).

Efferent pathway. — With respect to the efferent pathway, the results presented above demonstrate two points: 1) the fibres which convey the sudomotor impulses to the pinna leave the spinal cord below the C6 level, and 2) these fibres reach the sweat glands with the auricular vessels. The course of these fibres between spinal cord and pinna is partly know (4), since the ablation of the superior cervical ganglion abolishes this reflex (13). All these data and the sympathetic nature of the innervation of the sudoriparous glands, pointed out by LANGLEY (15, 16), show that the efferent pathway corresponds to the sympathetic (9, 14, 24).

Resumen

Se estudia en conejos blancos (New Zealand) la existencia de un reflejo electrodérmico no segmentario y la vía que sigue desde el borde del pie donde se aplica el estímulo térmico, hasta el pabellón auricular donde aparece —en un área determinada— la respuesta sudomotora. Su trayecto aferente, que se inicia siguiendo el n. plantar lateral y el n. tibial, discurre después por la red nerviosa perivascular de los vasos safenos, para penetrar en la médula espinal con el n. femoral. En la médula asciende ipsilateralmente, abandonándola por debajo del segmento cervical 6. La vía eferente del reflejo electrodérmico alcanza las glándulas sudomotoras del pabellón auricular por las fibras que acompañan la arteria que irriga el correspondiente territorio auricular. Estos resultados demuestran que el brazo aferente del reflejo pasa del nervio ciático al nervio femoral, utilizando como puente la red nerviosa perivascular, que en la médula espinal no sigue el haz espinotalámico, y que, aunque intervengan en el control de este reflejo electrodérmico centros supraespinales, su integración se desarrolla a nivel espinal.

Palabras clave: Respuesta electrodérmica, Estímulo algogénico, Reflejo podoauricular.

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