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TOPOGRAPHIC STUDIES OF DISTURBANCES OF SWEAT SECRETION AFTER COMPLETE LESIONS OF PERIPHERAL NERVES

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THE colorimetric investigation of sweat secretion has become of increasing interest in recent years, not only in the investigation of physiological problems, but also as a supplement to the existing methods of clinical diagnosis. It enables alterations in function of different parts of the nervous system to be identified both simply and exactly. As it does not depend on the patient's statements it is often superior to subjective methods and to the tedious method of chronaxie. This applies especially in cases in which partial lesions of a plexus are present and in following the successive phases of peripheral nerve regeneration after total blocking, suture, etc.

In previous papers (Guttmann and List, 1928 ; Guttmann, 1931, 1937) I have described numerous examples of the disturbances in sweat secretion which result from complete blocking of peripheral nerves. It has been shown that in general the area of sweat disturbance resembles that of disturbed sensibility and especially of analgesia, but that it has its own characteristic form and extent. Further observations have rendered it desirable to attempt a more precise analysis of the sweat disturbances in the areas of distribution of disrupted peripheral nerves.

In this connection a detailed investigation has been made of the following different zones. (1) *The autonomous zone* : that area, according to Foerster (1929) and others, in which loss of sensation and anhydrosis are complete

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following blocking of its nerve of supply. This area of skin is, therefore, that supplied solely by the blocked nerve. (2) *The mixed or intermediate zone* : that area which is supplied not only by the blocked nerve but also by those adjacent to it, and in which the loss of sensibility is only partial. Head (1908) describes it as a zone of protopathic sensation, Trotter and Davies (1909) as a zone of hypoesthesia. It appears in the "sweat-picture" in some cases as an area of hypohydrosis ; in others, especially in experiments with pilocarpine, as an area of hyperhydrosis. The extent of the mixed or intermediate zone of a peripheral nerve is actually larger than that found after total interruption. There is an area of supply which can only be demonstrated when the nerve itself is intact and all its adjacent nerves are totally interrupted. Foerster (1929) calls this part of the mixed zone the subsidiary zone. (3) *The maximal zone* : the complete area of distribution, or the sum of zones 1 and 2. The complete area of distribution of a peripheral nerve is only demonstrable when all the nerves supplying adjacent areas have been blocked. Sherrington and Head described the sensibility which persists after this procedure as "residual sensibility." As I was able to find an analogous area for sweating, I will call this the area of residual perspiration. As already mentioned these zones have attracted the attention of physiologists and neurologists in connection with disturbances of sensation following lesions of individual nerve-trunks (Létiévant, 1873 ; Head, 1905, 1908 ; Sherrington, 1892, 1898 ; Trotter and Davies, 1909 ; Foerster, 1929 ; v. Frey, 1894, 1896 ; and others).

The following method is largely topographic-physiological and has a certain significance in the investigation of the action of subcutaneous pilocarpine on sweat secretion in cases of a total interruption of peripheral nerves. This latter point is of physiological interest and has long been open to controversy.

The following investigations were carried out in the first instance by Minor's starch-iodine method, but in recent years exclusively by the chinizarin method.

The sodium salt of chinizarin 2-6-disulphonic acid is the colour indicator. This dye is a derivative of anthraquinone and, like alizarin, purpurin, and anthraruphin, is employed in the dye industry. On account of its affinity for water, chinizarin must be kept absolutely dry by admixture with sodium carbonate before it is applied to the skin. A mixture in the following proportions is the most suitable : sodium salt of chinizarin-2-6-disulphonic acid, 35.0 gm., sodium carbonate (powdered) 30.0 gm., rice starch 60.0 gm. For particular investigations it is possible to change these proportions. It is important that the ingredients should be quite dry, finely powdered, and thoroughly mixed. The resulting powder is of grey or reddish-grey colour. With a pad of cotton-wool the powder is dusted over the area of skin to be investigated, using moderate pressure to ensure that the orifices of all the sweat ducts become filled with powder. If the sweating is to be produced by sympathomimetic sudorific drugs, 5 or 10 grains of aspirin and one or two cups of hot tea are given before the powder is applied. The patient is then placed under the radiant heat cradle for a variable time, from 15 to 45 minutes, depending on the readiness with which sweating is obtained. During this time careful observations are made of the time of onset, distribution, and degree of sweat secretion, not only in the area of supply of the damaged nerve, but also in those of the adjacent nerves and the corresponding parts of the opposite side of the body. Where sweating occurs the skin takes on a dark blue-violet colour, and the openings of the individual sweat ducts appear as minute dark dots. The dry areas remain light in colour. This colour distinction lends itself to

photography. At the end of the sweating test the powder may be removed with warm water and soap, if necessary with the help of some vinegar.

Comparative experiments using the chinizarin method and other colorimetric procedures have been carried out by Böhm (1937), Plügge (1938), and myself (1937). There is general agreement that the chinizarin method is suitable and most simple.

The cause of interruption of peripheral nerves in the cases to be described was traumatic and the classical symptoms of complete loss of motor, sensory, and autonomic functions were present. In numerous cases the total interruption of nerve conduction was verified at operation.

Axillary nerve

Fig. 1a shows the result of a sweating-dye-test in a patient with complete interruption of the axillary nerve caused by dislocation and infraction of the head of the humerus. Besides complete absence of sensation in the autonomous zone of the axillary nerve (Fig. 1) a flaccid atrophic paralysis of the deltoid and teres minor muscles was present.

The test was carried out about 4 months after the accident and clearly demonstrated the various degrees of sweat secretion in the area of the distribution of the injured nerve. The anhydrosis in the autonomous zone of the axillary nerve is represented by the white field. The intermediate zone of hypohydrosis is represented in the picture by an area of dark and white spots and patches. The areas of marked sweating in the skin supplied by adjacent nerves appear particularly dark (perilesionary hyperhydrosis).

The variations in the extent and shape of the autonomous and intermediate zones of sweat disturbances following total interruption of the axillary nerve

a

b

FIG. 1.

FIG. 1.

are reproduced schematically (Fig. 1*c-e*). These drawings show that the shape and extent of the two zones vary according to the extent of the skin areas innervated by adjacent nerves. Cases 1*c* and *e* had a paralysis of the axillary nerve caused by a fracture of the head of the humerus. There was muscular atrophy with total loss of sensation in the autonomous zone. In Case 1*c* the interruption of the axillary nerve was verified at operation 6 months after the accident. In the case of Fig. 1*d*, there was also an incomplete lesion of the radial nerve with weakness of the extensor muscles of the wrist and fingers and

disturbances of sensation in the distal parts of the area of supply of the radial nerve, caused by a lesion of the right brachial plexus following a motor-car accident.

Following a peripheral nerve lesion the border area of the autonomous zone of a damaged nerve is sometimes revealed, especially in experiments after subcutaneous injection of pilocarpine, by a broad or narrow strip of hyperhydrosis. This is shown in one case (Fig. 1*f*) by the presence of some sweat secretion within the area of supply, indicating that the lesion of the axillary nerve is not complete. Apart from this sweat disturbance this case showed, 5 months after dislocation of the right humerus, an incomplete reaction of degeneration and a diminution of all forms of sensibility in the autonomous zone.

FIG. 2.

The maximal zone of the axillary nerve is only demonstrable after interruption of all adjacent nerves, i.e. supraclavicular, radial nerves, medial cutaneous nerve of the arm, and medial cutaneous and lateral cutaneous nerves of the forearm. This is shown in the following case, in which these nerves, with the exception of the supraclavicular nerves, have been interrupted (Figs. 2*a-c*). A young man, aged 18 years, while working at a machine had his right arm caught by a belt and was flung against an iron post, striking it with his right shoulder. Immediately after the accident there was a paralysis of the whole arm. A few days later the function of the deltoid muscle and of the flexors of the right hand and fingers recovered. The paralysis of the flexors and extensors of the forearm and the paralysis of the extensors of the hand, however, persisted and neurological examination 5 months after the accident showed a total interruption of the motor and sensory functions of the radial and musculocutaneous nerves. In addition there was an interruption of the medial cutaneous nerves of the arm and forearm. A complete anhydrosis in the areas supplied by all the completely interrupted nerves was revealed by the sweating test. The maximal zones of the remaining intact nerves, namely, the axillary and ulnar nerves, could therefore be demonstrated. This case shows how far the area of supply of the axillary nerve extends into the anterior and lower parts of the upper arm and how extensive is the area of "residual perspiration" of the axillary nerve. This case also shows the wide extent of the maximal zone of the ulnar nerve on the forearm after interruption of the three cutaneous nerves of the forearm, i.e. radial nerve, musculocutaneous and medial cutaneous nerves of the forearm.

Radial nerve

After complete lesions of the proximal part of the radial nerve, i.e. either above the dorsal cutaneous nerve of the forearm or after interruption of the whole radial trunk above the posterior cutaneous nerve of the upper arm, two types of sweat disturbance may be found. (1) The anhydrosis may comprise one continuous area, as shown in Fig. 3*a*. This occurred in a case of complete

FIG. 3.

motor and sensory interruption of the radial nerve above the dorsal cutaneous nerve of the forearm. The neurological examination was made 3 months after fracture of the humerus. Fig. 3a shows the continuous area of anhydrosis following the simultaneous interruption of the dorsal cutaneous nerve of the forearm and the dorsal cutaneous nerve of the hand. (2) On the other hand, in some cases of this combined lesion the continuity of the autonomous zone of these two branches of the radial nerve may be absent if there is a larger overlap of the neighbouring nerves. This is shown in Fig. 3b on the lower third of the forearm, where the medial and lateral cutaneous nerves of the forearm together with the ulnar nerve extend into the area of supply of these two branches of the radial nerve. In this case the interruption of motor and sensory functions of the radial nerve was caused by fracture of the humerus. The sweating test was made about 5 months after the accident. Likewise after simultaneous interruption of the most proximal branch of the radial nerve, the posterior cutaneous nerve of the upper arm, and of the dorsal cutaneous nerve of the forearm, the continuity of the anhydrotic areas may be absent, due to overlap of the medial and lateral cutaneous nerves of the arm. As the radial nerve supplies a very small area of skin on the upper arm such an interruption of continuity may be frequent in isolated lesions of the radial trunk.

The variations of the overlap by nerves adjoining the radial nerve on the forearm is shown in Figs. 3a-d. While Figs. 3a and b were from cases with isolated paralysis of the radial nerve, Figs. 3c and d were from cases in which there was also an interruption of the lateral cutaneous nerve of the forearm caused by stab injury (Fig. 3c) and gunshot injury (Fig. 3d). The two latter cases, therefore, demonstrate the variations of overlap by the ulnar nerve and medial cutaneous nerve of the forearm. In both cases total interruption of continuity of the radial nerve was verified at operation.

The maximal zone of the radial nerve is revealed by residual sweating in its whole area of supply if the adjacent nerves, especially the ulnar and median nerves, are paralysed. Thus, Figs. 4a and b illustrate the maximal zone of this

FIG. 4.

nerve in a case of total interruption of continuity of the median and ulnar nerves and the medial cutaneous nerve of the forearm, caused by a gunshot wound of the forearm. The lateral cutaneous nerve of the forearm has also been damaged in its lower part. There was paralysis of all muscles of the hand and fingers

supplied by the median and ulnar nerves, with marked atrophy of these muscles, and a contracture of the long flexors of the fingers. In addition, a complete loss of sensation in the area of supply of the severed nerve was found. The sweating test in this case was made eighteen years after the injury. Within the maximal zone of the radial nerve Figs. 4*a* and *b* show the varying degrees of sweat secretion; the uniformly black area corresponds to the autonomous zone of the radial nerve, and the marginal, patchy and dotted areas of staining indicate the subsidiary or mixed zone which is supplied in conjunction with the ulnar and median nerves. The autonomous zone of the radial nerve on the back of the hand is very small and lies chiefly between the thumb and index finger. The radial nerve also supplies the proximal phalanges of the middle and index fingers (Fig. 4*a*). This area, which shall be considered again in connection with the results of median nerve paralysis, derives a supply both from the radial and the median nerves; paralysis of one of these nerves in the majority of cases does not abolish sweat secretion in this area. In Fig. 4*b* the subsidiary zone of the radial nerve encroaches considerably upon the area of supply of the median nerve.

The maximal zone of a nerve may also be clearly revealed as a result of an "irritative" lesion of the nerve. Foerster (1929) showed in a study of disturbance of sensibility that the maximal zone of many nerves may extend beyond the areas in which the smallest branches are to be found by dissection. The maximal zone clearly revealed by the sweating test in a case of incomplete lesion of the radial nerve with "irritation" of the dorsal cutaneous nerve of the forearm is shown in Figs. 5*a* and 5*b*. This patient suffered from paralysis and

FIG. 5.

partial R.D. of the extensor muscles of his right hand and fingers, relative sensory loss in the area supplied by the dorsal cutaneous nerve of the hand, cutaneous tenderness and intense pain on the dorsal aspect of his right forearm. In addition, he himself noticed that the back of his right forearm was always wet, and the sweating test showed great hyperhydrosis in an area which corresponded

exactly with the area of cutaneous tenderness. This was presumably an irritative lesion of the dorsal cutaneous nerve of the forearm.

Median nerve

The disturbances of sweat secretion on the palm resulting from interruption of the median nerve are illustrated in Fig. 6a.

A butcher, using a sharp knife, accidentally cut the median nerve below the wrist. Within a few hours the nerve was sutured. Four weeks later examination revealed a palsy of the two muscles abductor pollicis brevis and opponens and a total loss of sensation in the autonomous zone of the median nerve. The sweating test showed as unstained the extent of the autonomous zone in the palm of the hand, thumb, index, and middle fingers (Fig. 6). The mixed zone of the median nerve was represented by the area of small black dots. This zone illustrates, therefore, the considerable overlap of the radial and ulnar

FIG. 6.

nerves upon the median nerve. Variations in the extent of the autonomous and intermediate zones on the volar surface of the hand following total lesions of the median nerve are shown in Fig. 7a—f. Fig. 7e shows results of the test in a subject who had a traumatic palsy of the lateral cord of the right brachial plexus with complete interruption of the median nerve. Figs. 7b, c, d, and f illustrate results in the presence of lesions of the median nerve above the wrist. Fig. 7a is the picture obtained following interruption by gunshot injury of the median nerve in the middle third of the forearm. The complete interruption of the continuity of the nerve was verified at operation.

It is evident that there is considerable variability in the size of the autonomous

and mixed zones of the median nerve. In some cases the autonomous zone may involve the greater part of the palm and the volar surfaces of the fingers with the exception of the little finger. In other cases the autonomous zone may be so small that the mixed zone of the ulnar and radial nerves on the palm may overlap it. The proximal border of the autonomous zone of the median nerve on the palm of the hand may come to a sharp point (Figs. 7*a* and *b*) or, take the form of a more or less blunt arch (Figs. 7*c* and *d*) at the junction of the radial and ulnar boundaries of the area of anhydrosis.

That the sweat glands of the ball of the thumb are supplied less by the median nerve than by the radial nerve has been demonstrated already in Fig. 4*b*.

FIG. 7.

The same fact is illustrated in Figs. 7*a* and *b*. Some participation by the radial nerve in the supply of the ball of the thumb is seen in Fig. 7*c*, while there is none in Figs. 7*e* and *f*. An interesting variation (Fig. 7*d*) is an area of very intense sweating on the ulnar side of the ball of the thumb, whilst the radial side of the thumb shows but little sweat secretion. The anatomical basis for this may be the well-known macroscopic anastomosis between the superficial branches of the ulnar and median nerves.

The anhydrosis on the volar side of the fingers following lesions of the median nerve involves the two phalanges of the thumb, the index finger and the median part of the middle finger. The ulnar side of the middle finger, together with the ring and little fingers and the lateral part of the thumb, are involved to a variable extent in the mixed zones of the median and its adjacent nerves.

How largely the median nerve may participate even in the supply of the volar surface of the little finger is shown by the extensive disturbance of sweat secretion following complete lesion of the median nerve (Fig. 7c).

Great differences in the extent of the autonomous zone on the back of the fingers are found following total lesions of the median nerve (Fig. 8a-f). In all cases the anhydrosis extends on the index finger distally from the middle or distal end of the proximal phalanx, on the middle finger in the majority of cases from the middle of the proximal phalanx. The distal part of the middle finger, especially on the ulnar side, may be within the area of supply of the ulnar nerve and show the presence of sweat secretion (Fig. 8f). On the back of the ring finger (Fig. 8a-f) anhydrosis and other disturbances of sweat secretion may be nearly absent (Fig. 8f).

FIG. 8.

Ulnar nerve

In all cases of total interruption of the ulnar nerve the median nerve was simultaneously involved to some extent. It is therefore only possible to consider the relations of the ulnar to the radial nerve on the back of the hand and the fingers. Figs. 9a and b and Fig. 4a illustrate the variations in the extent of the autonomous zone on the back of the little and ring fingers as well as on the back of the hand, which may be found after complete interruption of the ulnar nerve by gunshot injury in the upper third of the forearm. Figs. 4a and 9b show the mixed zone of the ulnar nerve with the radial nerve, and how extensive this

zone may be. A clear conception of the whole area supplied by the ulnar nerve on the back of the hand may be obtained from a comparison of Figs. 4a and 9a-b with Figs. 3a-d, which demonstrate the maximal zone of the ulnar nerve on the back of the hand after total interruption of the radial nerve. The proximal border of the maximal zone of the ulnar nerve in its whole extent may only be seen when the ulnar nerve and the medial cutaneous nerve of the forearm are severed. Thus, Figs. 2a and c show that the proximal part of the maximal zone of the ulnar nerve involves most of the ulnar side of the forearm, while its autonomous zone extends only 2-3 cm. above the wrist joint (Figs. 4a, 9a-b).

FIG. 9.

Common peroneal nerve

Figs. 10a-d illustrate the disturbances of sweat secretion following complete interruption of the common peroneal nerve. In the cases shown in Figs. 10a and b there was an isolated lesion of the peroneal nerve. In those shown in Figs. 10c and d the sciatic nerve was interrupted. The sweat secretion in the areas of supply of the tibial and sural nerves is preserved in Figs. 10a and b.

FIG. 10.

The area of supply of the sural nerve occupies the whole of the lateral part of the foot and extends with a sharp border to the medial side of the third toe. Fig. 10*b* differs from Fig. 10*a* in that there is an additional small area of sweat secretion at the proximal phalanx of the first and second toes. These charts illustrate the results obtained in the case of a young man who sustained a big hæmatoma of his right knee with a total motor and sensory paralysis of the common peroneal nerve (Fig. 10*a*) and in the case of a young flying officer who, on making a parachute landing, sustained in addition to a dislocation of his right knee a complete rupture of the common peroneal nerve, which was observed 16 months after the accident at operation (Fig. 10*b*). The subjects with lesions of the sciatic nerve suffered their injury following an intraneural injection in the one (Fig. 10*c*), and an injury from the tusks of a boar in the other (Fig. 10*d*).

The four cases show the relations of the common peroneal nerve to the adjacent nerves, especially to the saphenous nerve. The "sweat-pictures" illustrate the variability of the extent and shape of the autonomous and mixed zones of the peroneal nerve especially on its medial side where it overlaps the saphenous nerve.

Suprarorbital nerve

That the trigeminal nerve contains secretory fibres in its extracranial branches is now well established. Figs. 11*a-d* show the disturbance of sweat secretion

FIG. 11.

in lesions of the supraorbital nerve. After avulsion of this nerve with its frontal branches, performed in four cases, an area of anhydrosis always appeared shortly after operation. This area extended from the superior and medial to the lateral border of the orbit. While the medial border of the anhydrosis up to the edge of the hair line was constant in the majority of cases, there were considerable variations in the lateral border according to the extent of the

mixed zone with the auriculo-temporal nerve on the lateral part of the forehead. Thus in the majority of cases the autonomous zone of the supraorbital nerve only involves a small region above the medial third of the superior orbital border.

Summary

Colorimetric investigation of sweat secretion shows that after total interruption of a peripheral nerve the loss of sweating is complete only within the autonomous zone of the nerve.

The mixed or intermediate zone is revealed by more or less marked hypohydrosis. Following the administration of pilocarpine this zone shows an area of hypohydrosis.

The maximal zone of a peripheral nerve may be demonstrated (a) after section of all adjacent nerves (the area of residual sweating) or (b) by incomplete lesions of the nerve, characterized by pain and cutaneous tenderness and spontaneous sweating.

In the area of residual sweating the autonomous and mixed zones can be distinguished from each other by differing degrees of sweating.

The demonstration of the different zones in the sweat picture shows that there is great variability in the area of autonomous supply of each peripheral nerve and in the extent of overlap of adjacent peripheral nerves with one another.

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