Part II  Loss of significance of stimulus site

In previous investigations the relation between the normal and pathological plantar reflex was studied electromyographically, particular attention being paid to short-latency responses of definitely spinal origin, and to the reflex patterns obtained by simultaneous recording from the short hallux flexor and extensor (Kugelberg, Eklund, and Grimby, 1960; Grimby, 1963a, b; 1965).

In normal subjects these reflex patterns are closely correlated to the stimulus site so that the resulting response invariably represents the adequate reflex movement suitable for withdrawing the offended area from a noxious stimulus. In its main features this reflex coordination is independent of preceding conditioning stimuli, but in its more elaborate details it requires that the subject exposed to the stimulus expects it and knows where it will be applied. In the reflex pattern resulting from stimulation of the sole of the foot, flexor responses are dominant while extensor activity prevails on stimulation of the hallux ball. This contrast between the ‘plantar’ and ‘hallux’ patterns is as a rule close to maximal in healthy subjects with brisk reflexes but less pronounced in persons with sluggish reflexes.

As age advances, the threshold of the short-latency plantar reflex is raised (cf. Magladery, Teasdall, and Norris, 1958) and the adaptation of the reflex pattern to the stimulus site is reduced.

When the reflex mechanism is injured, extensor activity plays a more prominent role in relation to flexor, and the ‘contrast’ between the plantar and hallux patterns is reduced, although in some cases more, and in other cases less, than might have been expected from the amount of extensor activity in the plantar pattern. It was assumed (Grimby, 1963b) that different pathways might be involved in the suprasegmental reflex control and that these pathways might, independently of one another, be more or less affected by the pathological process.

The present investigation was undertaken to study how the correlation of the reflex pattern to the stimulus site may be affected by injuries of the nervous system of varying sites and degrees of severity.

MATERIAL AND METHODS

A total of 120 patients with disorders and injuries of the central nervous system were examined, using the methods previously described (Grimby, 1963a, b; 1965). Thus, painful stimuli consisting of a series of repetitive electric shocks delivered over a period of 10 msec. were applied to one spot on the hollow of the foot and to another on the hallux ball, and the resulting reflex responses were recorded simultaneously in the short hallux flexor and extensor.

The study was limited to discharges definitely not deriving from voluntary responses, as evidenced either by their brief latencies or by the patient’s inability to make voluntary toe movements. All remarkable results were confirmed by repeated experiments.

RESULTS

PATIENTS WITH PRESERVED MOTOR AND SENSORY FUNCTIONS  Observations were made on 50 patients with spastic symptoms in one or in both of the legs, but with well preserved voluntary toe movement and ability to perceive and localize a painful stimulus applied to the sole.

Most of these cases exhibited a distinct contrast between the reflex patterns obtained on stimulation of the planta and on hallux stimulation. In about half of the cases, flexor activity was dominant in the plantar pattern, the contrast to the hallux response being, as a rule, equally pronounced as in normal cases. In the other half of the cases the plantar pattern consisted either of alternating flexor-extensor, or of dominant extensor responses; in these cases, the contrast between the two reflex patterns was less pronounced, but still as a rule quite obvious, even when extensor responses were strongly predominant (Fig. 1).

In some cases there was no perceptible contrast between the two reflex patterns; in a few cases of mild spinal cord lesions, the contrast was lacking bilaterally; in a few cases of mild cerebral injuries, it was lacking only on the injured side.

PATIENTS WITH LOSS OF MOTOR AND SENSORY FUNCTIONS  The study included 15 cases with cervical or thoracic cord injuries causing total paralysis of the foot musculature and total anaesthesia of the sole; the duration of the lesions ranged from days to months or years. The subjects were young or middle-aged persons of the same age groups as the normal subjects previously examined (Grimby, 1963a). Before the injuries, the reflex patterns could be presumed to have been virtually pure flexor on plantar, and pure extensor on hallux stimulation with next to maximal contrast between the two patterns (viz. patterns of the types in Fig. 1 A and B).
As long as the effective stimulus strength and other experimental conditions were kept constant, the reflex pattern remained unchanged when the stimulus was shifted from the hallux to the sole. On moderate stimulation the responses were either virtually pure extensor (six cases, Fig. 2 A), pure flexor (two cases, Fig. 2 B), or alternating flexor and extensor (seven cases, Fig. 2 C).

In the patients with severe spinal injuries, the reflex pattern always varied from one stimulation to the other. All types of reflex pattern elicitable on plantar stimulation could be obtained also on stimulation of the hallux, but no attempts were made to determine the relative incidence of predominant flexor and predominant extensor responses at the two regions of stimulation. Instead of being corre-
related to the stimulus site, the reflex pattern was dependent on factors which were irrelevant from a protective point of view. In two cases, dominant extensor activity invariably resulted on strong, and alternating flexor and extensor activity on weak, stimulation, which well agrees with early clinical observations (Walshe, 1914; Riddoch, 1917). In one case the reflex pattern could be varied by changes in the position of the leg; this accords with previous observations in man (Dosužkov, 1932) and animals (Perl, 1962). In most cases the reflex pattern varied with factors beyond the experimenter's control.

**Patients with loss of voluntary power** The study included 26 cases with loss of voluntary power to plantar- or dorsiflex the hallux but with preserved ability to feel and localize painful stimulation of the sole. Out of these patients, nine had spinal cord lesions, six internal capsule lesions, eight cortical injuries, and three psychogenic pareses with no organic symptoms. The motor disturbances were equally pronounced in the different groups, while the sensory impairment was marked in the cases of spinal cord and internal capsule lesions but only slight in the cases of cortical injuries.

Patients with spinal lesions exhibited no regular contrast between hallux and plantar patterns, the only exception being a case of monoparesis due to a relatively mild cervical injury, and in this case the contrast between the two reflex patterns was considerably reduced, as judged by the condition of the contralateral leg. The patterns obtained on moderate stimulation consisted of virtually pure extensor activity in half of the cases, and in the other half of alternating flexor and extensor responses.

In the patients with internal capsule lesions, no contrast was observed between the hallux and plantar patterns. Characteristic of the group is the pattern illustrated in Figure 3. This patient had a total hemiplegia caused by a minor bleeding in the internal capsule. On the normal side, plantar stimulation gave pure flexor, and hallux stimulation pure extensor responses (A). Before the injury the reflex pattern could be presumed to have shown the same maximal contrast bilaterally. On the injured side, strong stimuli gave pure flexor (B), and weak stimuli dominant extensor activity (C) independently of the stimulus site. Dominant flexor patterns were more readily obtained on plantar stimulation, and extensor patterns on hallux stimulation. This may have been due to the stimulus site as such, but may also be ascribed to the lower threshold of the planta; however, all variants of patterns which could be elicited at one stimulus site could also be evoked at the other site of stimulation.

In the patients with cortical lesions, the contrast was well preserved in two but entirely absent in three cases; in three cases the affected side showed a distinct, although in relation to the normal side considerably reduced, contrast. In one patient with unilateral cortical injury, plantar stimulation gave a reflex pattern of bilaterally dominant flexor, and hallux stimulation one of bilaterally equally dominant extensor, activity. An injury may thus give rise to total loss of the voluntary power and still have no perceptible effect on the reflex pattern. In one case of bilateral total paresis, the reflex pattern was correlated to the stimulus site on the less affected side, but not on the more severely affected side. The fact that persistence of contrast has been observed in cases of total cerebral, but not in total spinal, pareses cannot thus be ascribed to the former being usually unilateral and the latter usually bilateral.

In the cases of hysterical pareses no deviations from normal were observed.

**Patients with loss of pain perception** Finally, observations were made on 11 patients who could move their toes, although with more or less difficulty, but had lost their ability to perceive a moderately painful plantar stimulation, due to lesions of the central nervous system.

Beside the sensory loss, four patients also exhibited considerably impaired motor functions. In these, the reflex pattern was not correlated to the stimulus site. In three of the patients the motor symptoms alone were so severe that one would expect the contrast to be absent; in one patient with a partial unilateral cord lesion the contrast was, however, present on the strongly paretic side, and absent on the analgesic but only slightly paretic side.

Four patients exhibited sensory loss with virtually no motor disturbances. In these patients, the reflex threshold was extremely high and the responses obtained so weak that it was impossible to judge whether there was any contrast between the plantar and hallux patterns. In one patient with hemianalgiesia, with brisk reflexes on the normal side, no activity could be discerned on the injured side, although, due to a technical error, supramaximal stimuI of a duration of a second or more happened to be applied; the stimuli were strong enough to cause burns and should have given rise to vigorous defence reactions.

Psychogenic analgesia in the legs was studied in three patients. In two of these cases the responses obtained were practically normal, but in one case the reflex threshold during the period of analgesia was nearly as high as in the organic cases but became normal as soon as the analgesia had disappeared after psychiatric treatment.
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DISCUSSION

When the reflex mechanism is injured, the amount of extensor activity in the reflex pattern may increase and the purposeful protective correlation of the motor pattern to the stimulus site is reduced. A marked tendency to such a correlation may be maintained even when extensor activity is strongly dominant (Fig. 1). The adaptation to the stimulus site may, however, be entirely absent even in cases with a normal amount of extensor activity (Figs. 2 B and 3 C). Since these two types of changes may occur independently of one another, they must be an expression of different kinds of lesions of the reflex mechanism.

The contrast was invariably absent in cases of total transection or very grave lesions of the spinal cord. The technique employed was not sensitive enough to permit the conclusion that, in these cases, the influence of the stimulus site on the reflex pattern

FIG. 3. Case of unilateral internal capsule bleeding with total hemiparesis. A1, hallux pattern, and A2, plantar pattern on the non-paralytic side. B1, hallux pattern and B2, plantar pattern on the paralytic side elicited by strong stimulation. C1, hallux pattern and C2, plantar pattern elicited by weak stimulation. Upper tracings from flexor hallucis brevis, lower tracings from extensor hallucis brevis. Time 20 msec. Significance of stimulus site is abolished on the injured side although both dominant flexor and dominant extensor patterns can be obtained.
was entirely absent, but it can safely be concluded that the stimulus site was no longer prevalent over other factors which, although irrelevant from the point of view of defence reactions, might influence the pattern (cf. above). Even though the material studied is small, all types of cord lesion are represented in it, and it can be presumed, as a general rule, that in human cases of total cord transection the contrast between plantar and hallux patterns is abolished, independently of the level and duration of the lesion.

In earlier studies of the significance of the stimulus site for the nociceptive reflexes in human cases of total cord transection, purely clinical methods have been used and attention has mainly been devoted to the relation between the general flexor and extensor reflexes in the leg. With few exceptions (e.g., Riddoch, 1917, case 1) no purposeful adaptation to the stimulus site after cord transection has been described. Several researchers (Kuhn, 1950; Pollock, Boshes, Finkelman, Chor, and Brown, 1951; Marshall, 1954) have, however, found that the tendency to flexion of the leg is most pronounced on distal stimulation, and the tendency to extension on proximal stimulation, a variation with the stimulus site which bears a certain resemblance to the purposeful integration of normal reflexes (Kugelberg et al., 1960). When the supraspinal connexions are severed, it would seem as though the coordination of the flexor and extensor reflexes in the leg would suffer less than that of the hallux reflexes. This agrees well with the fact that cerebral factors are of less importance for the coarse features than for the finer adjustment of the normal reflex integration.

It has long been known (Sherrington, 1906a) that spinal cats and dogs may have remarkably well functioning cutaneous reflexes. This is contrary to what has been found in human subjects with spinal cord transection, but the difference is explicable on the ground that spinal centres become more dependent on cerebral functions, the higher the development of the species (Sherrington, 1906b; Riddoch, 1917). In electrophysiological studies of the nociceptive reflexes in the hind limbs of acute and chronic spinal cats, several authors (Hagbarth, 1952; Holmquist and Lundberg, 1961; Megirian, 1962) have observed that these reflexes are, even in their more elaborate details, dependent on the stimulus site; the experimental arrangement used by these researchers did not permit a direct study of the actual ensuing movements, but to judge from the results, the reflexes implied a movement designed to withdraw the limb from the noxious stimulus. The results obtained in the present investigation are, however, not directly comparable with theirs, since by their technique even very weak correlations between reflex direction and stimulus site could be revealed, viz., factors irrelevant for protective purposes could be preponderant.

In patients with severe cerebral lesions the contrast is absent; it must thus be a result of cerebral influence on spinal reflex centres. The contrast may be abolished even in cases of lesions at such high levels that the connexions between the brain-stem motor centres (cf. Nyberg-Hansen and Rinvik, 1963) and the spinal reflex centres can be presumed to be intact. Thus, the cortex seems to be of essential importance for the purposeful coordination of the reflex pattern.

The cortical influence giving rise to voluntary withdrawal movements must be expected to be closely related to that resulting in the purposeful integration of the reflex pattern. It is thus surprising that even in cases of total loss of the voluntary toe movement, the contrast between plantar and hallux patterns can be intact. There is so far no explanation for the discrepancy between voluntary and reflex power. An entirely intact reflex pattern contrast, despite total paresis, was observed only in patients with cortical lesions. Voluntary power may be governed by higher cortical centres than is the reflex motor activity. Even in spinal cases the reflex pattern contrast was, however, not always abolished simultaneously with the loss of voluntary power. The two motor functions may be transmitted through different corticospinal pathways. Bucy (1957) has shown that large parts of the pyramidal tract may be injured without impairing voluntary power and the reflex control may be transmitted through these pathways.

When pain perception is lost in the sole of the foot, the power to make a reflex movement of sufficient strength is abolished, and the ability to give the reflex an adequate direction is probably reduced. The organism has thus difficulties in utilizing the reflex system for protective purposes unless higher cerebral centres are continually provided with relevant information from the periphery.

Of clinical interest is, above all, the question to what extent studies of the contrast between the plantar and hallux patterns may be able to provide some practical diagnostic information. The normal variations in the amount of contrast present in the reflex pattern are wide, and even in healthy subjects the contrast may be too weak to be revealed by the technique used in these studies (Grimby, 1963a). An absent reflex pattern contrast is thus not per se evidence of an injured reflex mechanism. In normal subjects there are, however, no perceptible differences between the reflex patterns obtained bilaterally, and a unilateral loss of the contrast should thus be of diagnostic significance. An absent contrast is the
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disturbance most regularly observed in the reflex pattern when the supraspinal connexions are severed, but as a rule the contrast is not abolished unless the underlying lesion is fairly severe. In the individual clinical cases, studies of the contrast are thus only exceptionally likely to furnish diagnostic data that cannot more readily be obtained by other methods.

SUMMARY

The 'reflex patterns' obtained by simultaneous electromyographic recording in the short hallux flexor and extensor on application of punctiform electric painful stimuli of a duration of 10 msec. to the hollow of the foot and to the hallux ball, respectively, were studied in 120 patients with lesions of the central nervous system.

In normal subjects, flexor activity is dominant in the reflex pattern on stimulation of the planta, and extensor activity on hallux stimulation. When the reflex mechanism is injured, the amount of extensor activity in the reflex pattern may increase, and the contrast between the 'hallux' and 'plantar' patterns is reduced.

The present investigation was undertaken to study how the contrast between the hallux and plantar patterns may be affected by injuries of the nervous system of varying degrees of severity and at various levels.

1 The contrast might be preserved or abolished in patients with plantar patterns of strongly dominant extensor activity, as well as in patients with plantar patterns of dominant flexor activity. The reduction of the contrast must be an expression of another type of impairment of the reflex mechanism than that giving rise to an increased amount of extensor activity.

2 The contrast might be abolished in cases of cerebral hemispheric lesions and was invariably absent in cases of total cord transection. It was presumed that the contrast is dependent on a cerebral, most likely cortical, influence on spinal reflex centres.

3 Loss of the voluntary toe movement was usually accompanied by loss of the contrast. Cases occurred, however, with well preserved contrast despite total paralysis of the toes.

4 Loss of sensibility in the sole of the foot was accompanied by a marked rise of the reflex threshold and probably also by a reduction of the contrast.

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