ELECTROPHYSIOLOGICAL RESULTS CONCERNING THE CONNECTIONS BETWEEN THE PALLIDUM AND OTHER PARTS OF THE CENTRAL NERVOUS SYSTEM IN MAN

I. CONNECTIONS BETWEEN THE PALLIDUM AND THE CEREBRAL CORTEX

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Extensive afferent and efferent connections between the globus pallidus and other parts of the central nervous system have been demonstrated both anatomically and physiologically [2, 8, 15, 16]. However, some of them which are demonstrable by some methods have not been confirmed by others.

In the last two years, in the neurosurgical unit of the Moscow Order of Lenin S. P. Botkin Hospital, 35 operations have been performed in which the globus pallidus has been destroyed stereotactically in patients suffering from Parkinsonism and other forms of damage to the extrapyramidal pathways, where there was reason to suspect disfunction of the pallidum. In 15 of the patients it was possible to record the electrical activity of the globus pallidus and the cortex at operation. In this way, some opinion could be formed of the functional connection of the globus pallidus with other parts of the central nervous system, and in particular with the cortex, and certain features of the electrophysiological manifestations could be determined.

METHOD

By means of the stereotactic apparatus designed by Cooper [7], or by Fairman [12] a polyethylene cannula was introduced into the human globus pallidus; it had a metal core which protruded 1 mm from the end, and served as a lead-off electrode for recording electrical activity of the pallidum. In addition, records were made of the electroencephalogram (EEG) and the electromyogram of the muscles of the arm, and at the same time observations were made on the clinical effects. Recordings were made by ink-writing electroencephalographs, either of Soviet make, or made by the firm "Alvar". The globus pallidus was suppressed functionally by the injection of 0.5-1 ml of novocaine followed by 0.7-1 ml of 96% alcohol.

In most cases, introduction of a needle into the globus pallidus causes signs of its excitation, and the subsequent injection into this region of novocaine causes a temporary loss of function; when it is followed by alcohol, a necrosis occurs. The clinical manifestations are chiefly a reduction in tone, and a reduction or cessation of the hyperkinesis of the opposite limbs.

RESULTS

As has been shown by several workers [1, 3, 4, 11 and others], the initial EEGs of patients with Parkinson's syndrome show considerable variation. We found that sometimes the EEG was nearly normal, and showed a well-marked α-rhythm, and sometimes there was desynchronization. Our attention was drawn to an EEG where the α-rhythm was well shown, but its distribution was abnormal: it preponderated in the frontal lobes, and was desynchronized in the posterior lobes. In most cases (in 27 of the 35 operated patients), a Θ-rhythm preponderated. From its nature and distribution in the cortex, we distinguished two types of Θ-rhythm.

In the first type, we include a Θ-rhythm which was observed in the hemisphere on the same side as the damaged basal ganglia. It consisted of oscillations of constant amplitude, following continuously on each other, and alternating with other rhythms (Fig. 1a). In cases of bilateral Parkinsonism, the Θ-rhythm was recorded in both hemispheres. However, when there was considerable damage to the basal ganglia of one hemisphere, the Θ-rhythm was then more strongly shown in the cortex of that side.

A second type was quite different, and consisted, as a rule, of paroxysmal, often high-amplitude, bilaterally synchronized Θ-oscillations in the frontal lobes (Fig. 2a).

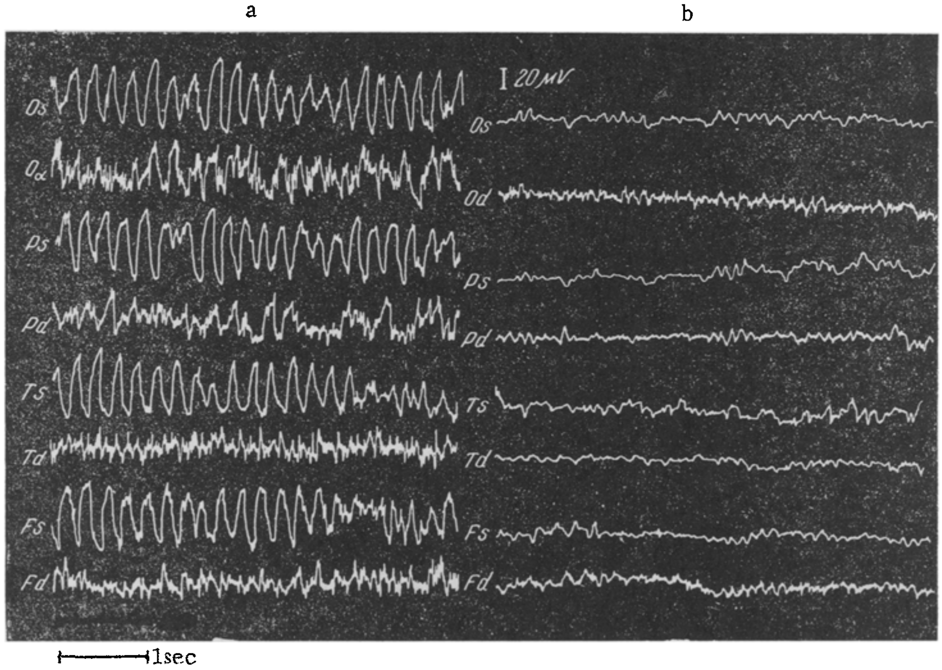

Fig. 1. Spread of the Θ-rhythm in a hemisphere with homolateral damage to the basal ganglia (a), and its disappearance after inserting a needle into the pallidum (b). The same picture results after destruction of the pallidum with alcohol. Os) left occipital area; Od) right occipital area; Ps) left parietal area; Pd) right parietal area; Ts) left temporal area; Td) right temporal area; Fs) left frontal area; Fd) right frontal area.

In response to the stimulus of the introduction of the needle into the pallidum, atypical forms of the rhythms described occurred. If, in the initial EEG, the α-rhythm was well shown, then each time the needle was inserted it caused a desynchronization, which chiefly affected the hemisphere of that side. If in the initial EEG there was no α-rhythm, then, when the needle was introduced there was a marked synchronization, which was frequently more marked on the opposite side. Also, in cases when the α-rhythm was best shown in the frontal regions, introduction of the needle led to a normal α-rhythm distribution. Both the homolateral (Fig. 1b) and the bilateral synchronous (Fig. 2b) Θ-rhythm disappeared when the needle was introduced. The effect could be repeated. If the needle was withdrawn and alcohol not introduced, the Θ-rhythm (and the desynchronized α-rhythm) returned. In cases of marked bilateral Parkinsonism, when the homolateral Θ-rhythm was recorded in both hemispheres, introduction of the needle into the pallidum of one hemisphere caused the Θ-rhythm of that side to disappear. In the opposite hemisphere, there were two possible responses: In some cases the Θ-rhythm remained unchanged, or else became more marked, while in other cases it was reduced, or even disappeared temporarily.

After the injection of alcohol into the pallidum, the changes in the EEG were somewhat different. The homolateral Θ-rhythm disappeared, just as it did after the introduction of the needle (see Fig. 1b), and the change was maintained for several months after the operation, particularly in cases where the clinical effect had been good. On the other hand, the bilateral Θ-rhythm in the anterior regions, which had disappeared after the introduction of the needle, recovered after the injection of alcohol, and was quite frequently as well shown as it had been originally (Fig. 2c); in most cases, after the alcohol injection, the α-rhythm also recovered to its original condition. Sometimes, however, the frequency was reduced (for example from 12 to 8 oscillations per second), an effect which has been reported elsewhere [6, 11].

It is important to point out that in all cases of elimination of the globus pallidus at operation, in the posterior regions of the homolateral hemisphere a Δ-rhythm developed, and then gradually disappeared over a period of several months. If the Δ-rhythm developed immediately after the injection of alcohol, it was first recorded from the pallidum, and then synchronously with the pallidal Δ-waves in the cortex.

All the EEG changes described above induced by stimulation or elimination of the pallidum confirm the existence of connections between it and the cortex.

However, the paths along which these connections are made appear to be various.

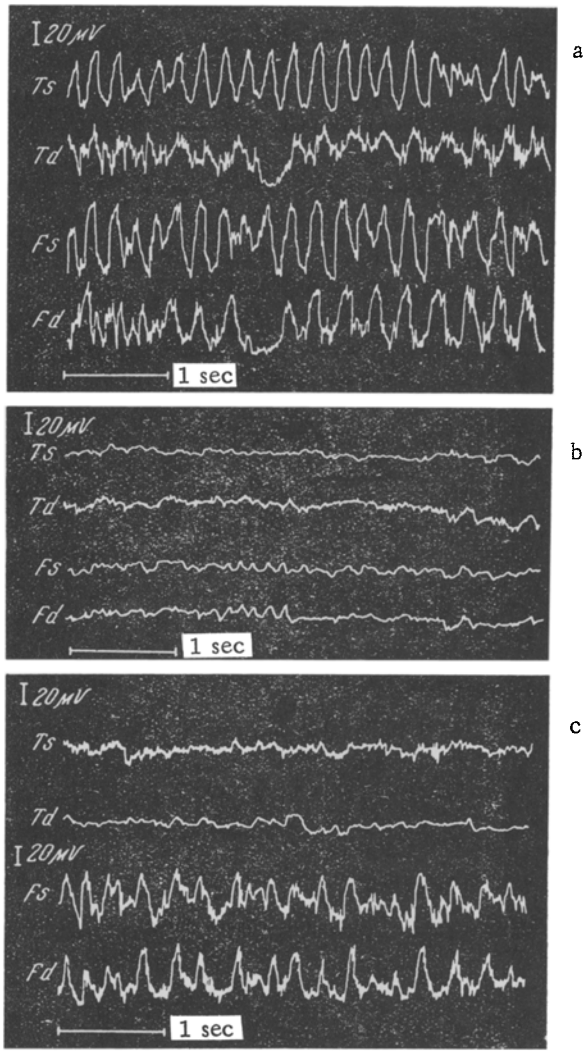

Fig. 2. Recording of bilateral Θ-rhythm in anterior cerebral cortex: a) before (presence) and b) after (absence) insertion of needle into the pallidum; c) recovery of bilateral Θ-rhythm in frontal regions after destruction of the pallidum with alcohol; Ts) left temporal region; Td) right temporal region; Fs) left frontal region; Fd) right frontal region.

The disappearance of the homolateral Θ-rhythm, both when the needle was introduced into the pallidum and when the latter was coagulated with alcohol, indicates the existence of a direct connection between the pallidum and the cortex of the same side. This fact does not exclude the possibility that the rhythm might reach the cortex not only from the pallidum but also from other subcortical structures, in particular from the thalamic nuclei, and that from them it would then pass through the pallidum to the cortex; in such a case, blocking the pallidum should eliminate the influence of the thalamus on the cortex through these pathways.

The influence of the pallidum on the bilateral synchronized Θ-rhythm is probably exerted through other pathways. According to published reports, the bilateral synchronous rhythm in the frontal regions is associated with the rostral portions of the brain stem [12, 17—for animals, 10, 19, 20—for man]. The disappearance of this rhythm from our patients after stimulation of the pallidum appears to indicate an influence from the latter onto the anterior regions of the cortex which is exerted through the thalamic nuclei, whose close connection with the pallidum has been demonstrated. The recovery of the bilateral Θ-rhythm after elimination of the pallidum (and hence after cessation of influences emanating from it) confirms the existence of a functional connection between the pallidum and the frontal cortical regions, involving the rostral thalamic portions of the brain stem.

The synchronization of the α-rhythm, which is sometimes observed when the pallidum is stimulated by the needle, is probably the result of an influence of the pallidum on the brain stem (on the reticular formation). The evidence, which is in line with published reports [17, 19], is the simultaneity of the synchronization in both hemispheres. The same influences may probably explain the return to normal of the distribution of the α-rhythm in the cortex caused by pallidal stimulation (occipito-frontal gradient). The transient appearance of a Δ-rhythm in the posterior areas of the operated hemisphere is probably due to trauma of the pallidum.

The conclusions to be drawn from the present investigation mainly concern the Θ-rhythm. We have confirmed the opinion of most present-day authors, who maintain that the Θ-rhythm is physiological in nature rather than physical [5, 11, 14, 18, 19]. Evidence for this view is supplied by the following facts: 1) the Θ-rhythm develops in certain, often quite limited areas; 2) the regularity and the great constancy of the response of the Θ-rhythm to specific influences; 3) the recording of a nearly normal EEG in many patients afflicted with a considerable tremor; 4) cases of disappearance of the Θ-rhythm in the cortex after coagulation of the pallidum, while the tremor is maintained (the electrodes were placed in the same position as for coagulation); 5) disappearance of the Θ-rhythm in the leads joined to the deep electrode, and its gradual shift from the pallidal structures; 6) the successive spread of the Θ-rhythm during its generalization into different areas of the brain.

With regard to the clinical value of the EEG results, we agree with England, Schwab and Peterson [10] that in Parkinsonian patients, the EEG is a good prognostic sign of the effectiveness of operation upon the globus pallidus. However, unlike them, we do not consider the Θ-rhythm in the cortex to contraindicate operation, because it is evidence of pathological changes of long standing. We have observed good and prolonged positive effects from operating on patients who showed a pronounced cortical Θ-rhythm.

The occurrence of synchronous bilateral Θ-waves in the frontal regions, and also the presence of a marked α-rhythm over the frontal lobes and its absence over other areas of the cortex, may perhaps indicate damage to thalamic structures. Cooper and Polukhin [9], and Walter, Rand and Ross [20] have shown that coagulation of the pallidum is particularly effective when it is followed by coagulation of the ventrolateral thalamic nuclei.

SUMMARY

Various EEG changes were noted during chemopallidectomy in patients with Parkinsonism and other extrapyramidal affections. Among these the changes in the two types of Θ-rhythm attract particular attention. Disappearance of the homolateral Θ-rhythm (type I) affected basal ganglia in pallidum stimulation and its exclusion points to the existence of a unilateral connection with the cortex of the homolateral hemisphere. Disappearance of the bilateral Θ-rhythm (type II) in the anterior portions of the cortex after pallidum stimulation and its restoration after pallidum exclusion point to the functional relationship of the pallidum to the anterior portions of cerebral cortex through the rostral portions of the stem with which bilateral synchronism is connected.

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