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The Corpus Callosum, Interhemisphere Interactions, and the Function of the Right Hemisphere of the Brain

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A complex clinical-neuropsychological study was performed by the Luriya method before and after surgery in 36 patients with arteriovenous malformations (AVM) of the corpus callosum. The symptoms of local lesions to the various parts of the corpus callosum are described. Symptoms of partial lesioning of the corpus callosum were found to be modality-specific, though only relatively. The symptoms of dyscopia or dysgraphia could appear in isolation fro each other. Combined lesions of the medial parts of the brain (cingulate cortex, frontal lobes) and the corpus callosum significantly increased the level of dysfunction of these medial parts. Patients with lesions to the anterior parts of the corpus callosum showed symptoms of frontal lobe dysfunction. Lesions to the corpus callosum led to dysfunction of the right hemisphere in the spheres of emotion, perception, and spatial activity. Previous studies have demonstrated that the right hemisphere integrates impulses from both sides of the space and is the first zone involved in activity, performing its initial stages. The author believes that this synthetic activity of the right hemisphere, with tight connections with the "conscious" left hemisphere, is required for the formation of the overall conceptualization of both individual objects and particular types of activity. From this point of view, it is the right hemisphere that can, in a sense, be regarded as dominant, rather than the left hemisphere.

KEY WORDS: corpus callosum, interhemisphere interactions, disconnection symptoms, right hemisphere function.

The corpus callosum is the largest commissure of the brain. Callosal fibers have been shown to connect homotypic (symmetrical) areas of the cortex in the two hemispheres; fibers in the splenium of the corpus callosum run to the occipital areas, and fibers in the body of the corpus callosum run to the temporal and parietal lobes; interhemisphere fibers of the frontal parts of the neocortex, located in the rostral parts, form the genu and rostrum of the corpus callosum [2]. In humans, as compared with other mammals, the corpus callosum also has a significantly larger number of fibers connecting non-symmetrical (heterotypic) areas of the associative cortex of the brain [14]. This type of corpus callosum structure is extremely important for further explanation of the characteristics of the symptomatology of the patients studied here.

Syndromes resulting from lesions to the corpus callosum in humans and animals were not identified for a long period of time. Sperry [29] noted that the corpus callosum had long had the reputation as the largest and most unimportant structure in the brain. Laschly [13] only assigned it a mechanical function.

Basic data on the functions of the corpus callosum were obtained from studies of patients undergoing transection of this structure for the treatment of incurable epilepsy. The theoretical basis for this operation was the suggestion that transection of the corpus callosum would prevent interhemisphere propagation of epileptic discharges.

The first sagittal transections of the corpus callosum were performed in 1940 by Van Eagenen and Herren [30] in 24 patients.

Detailed psychological studies of these patients were not undertaken, though impairment of coordination of movements of the left and right hands was noted.

Isolated commissurotomy was later found to be clinically ineffective, and deeper splitting of the brain came into use for the treatment of epilepsy, i.e., transection of the corpus callosum was supplemented with transection of the

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anterior, hippocampal, commissure and the interthalamic adhesion.

Results of detailed neurological and psychological investigations of patients after complete callosotomy have been described by many American authors [19–21, 23–26, 29, 31]. Even simple familiarity with these patients reveals a series of characteristics. Thus, Bogen [21] reported that commissurotomy was followed by a variety of "dissociative" phenomena, such as dissociation between the patient's facial expression and what he or she was communicating, between general actions (walking, running) and speech content, and between what was said and what was being done with the left hand. Intermanual conflict was entirely characteristic in the early post-operative period. Thus, one of the patients tried to use the two hands to do up and undo a shirt button at the same time. We note that the incorrect action in right-handers was always performed with the left hand. In fact, "the left hand did now know what the right hand was doing." The symptom was similar to the "foreign hand" phenomenon.

Many features of the functioning of "split brain" patients were identified in special psychological experiments in which a stimulus was presented to only one hemisphere.

A group of phenomena associated with the absence of speech functions in the right hemisphere (in right-handers) was very marked. Thus, patients could not name an object placed in the left hand (tactile anomy), but could recognize it and select it from a series of objects; they could not perform silent reading of letters or words presented tachyscopically to the left field of vision (unilateral alexia), but again, if the word identified an object placed among others, they could recognize the specified object by touch with the left hand. Patients could not write or copy letters with the left hand (dysgraphia). In conditions of dichotic hearing, patients completely ignored words presented to the left ear. In all these cases, information arrived in the "non-speech" right hemisphere. Transmission of spikes from this to the left, "speech," hemisphere was impossible after commissurotomy, resulting in these phenomena.

On the other hand, patients could provide verbal descriptions of objects placed in the right hand, but were unable to identify how they perceived it. Similarly, they were able to name an object whose image was presented tachyscopically to the right visual field, i.e., addressing the left – "speech" – hemisphere, but were unable to recognise the object by touching it with the right hand. Patients subjected to commissurotomy could not copy or draw with the right hand (dyscopia, unilateral constructive apraxia). These abnormalities were explained by impaired transmission of the gnostic properties of objects to the right hemisphere via commissural pathways.

Thus, studies of humans with commissural transection provide clear evidence of the main characteristics of the functional asymmetry of the brain identified by other study methods.

Clear support for the functional asymmetry of the brain in patients subjected to commissurotomy provided the grounds for suggesting that there are two isolated spheres of thought, two types of brain: the left hemisphere, operating with verbal stimuli and working on the basis of logic, and the right hemisphere, associated with indirect perception. Gazzaniga [6] believed that each hemisphere, working independently, could process twice as much information without losing time transferring it to the other hemisphere. However, the point of view that each hemisphere can operate in completeness after callosotomy met with very serious objections based on experimental and clinical data.

The symptoms characteristic of post-commissurotomy patients and seen in complex investigations have also been described in patients with lesions to the corpus callosum of other etiologies. These lesions included partial lesions (infarcts, tumors, adhesions). It is important to emphasize that "split brain" symptoms in these conditions were incomplete and dependent on the location of the lesion focus in the corpus callosum. The modal specificity of corpus callosum lesions was clearest in patients with arteriovenous malformations (AVM) located in the depth of this structure [15, 17].

To summarize these data, the major studies on corpus callosum pathology are based on investigation of functions in response to presentation of stimuli addressing a single hemisphere. A few reports describe studies of individual functions (memory) in response to presentation of information simultaneously to both hemispheres (in standard psychological experimental conditions) [31]. The question of the overall formation of individual higher mental functions in conditions of hemispheric disconnection and the lateralizing characteristics of impairments arising in these conditions thus far remains to be resolved. In other words, we have attempted to determine whether the functions of one hemisphere are affected more than those of the other after lesions to the corpus callosum.

The aim of the present work was to evaluate impairments of higher mental functions in patients with partial lesions to the corpus callosum.

MATERIALS AND METHODS

Complex clinical-neuropsychological studies were performed before and after surgery in 36 patients with AVM of the corpus callosum. The distribution of patients in terms of the locations and malformations is shown in Table 1. In seven patients with lesions of the posterior parts of the corpus callosum, AVM equally affected the corpus callosum and the cingulate gyrus.

Most of the patients (30 of 36) were aged 16–35 years. All patients had sustained hemorrhages at times from several months to several years before admission to hospital. Strict verification of the locations of brain lesions was per-

TABLE 1. Locations of AVM of the Corpus Callosum

Areas	Right	Left	Midline	Total
Anterior (including the genu)	3 (2)	4 (2)	2 (2)	9 (6)
Intermediate	1 (0)	5 (5)	1 (1)	7 (6)
Posterior (including the rostrum)	9 (8)	11 (9)	–	20 (17)

Notes. Numbers in parenthesis are numbers of patients.

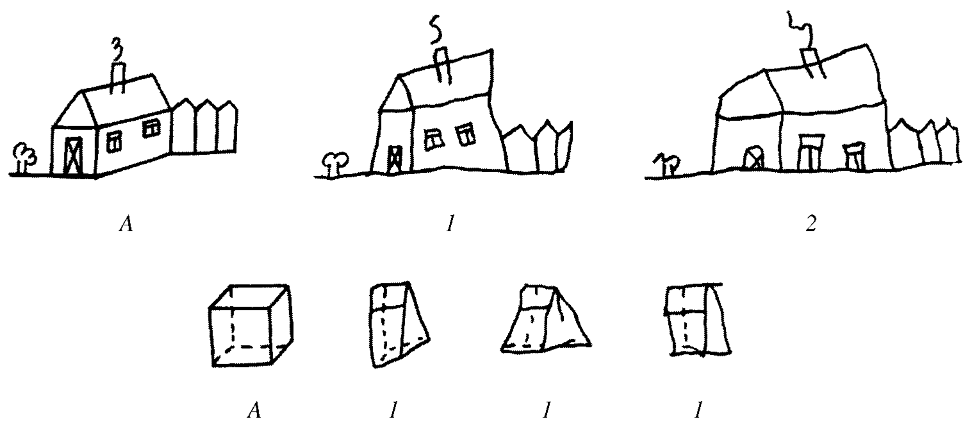

Fig. 1. Copying by patient R. before surgery. *A*) Images. *1*) Copying with the right hand; *2*) with the left hand. For explanation see text.

formed in all cases, using angiography and CT scans, as well as by observation during surgery.

In clinical practice, unlike the experimental situation, it is difficult to identify a group of patients with local lesions to a particular structure. Our patients with AVM are no exception to this rule – before admission, all had sustained hemorrhages. We therefore excluded patients with deep hemispheric neurological symptomatology as well as those in whom these signs appeared post-operatively. Symptomatology due to combined lesions of the corpus callosum and adjacent brain structures (the cingulate gyrus, the mediobasal parts of the frontal lobes) were analyzed separately.

All patients were examined during the course of treatment using the method of Luriya [12], as we have described previously [4]. Left-handedness was identified using the Dobrokhotova and Bragina questionnaire [9]. Only one of our patients was an unretrained left-hander; 13 had signs of left-handedness and left-handed relatives (genetic left-handedness); the remainder were right-handed.

RESULTS AND DISCUSSION

Before surgery, 28 of the 36 patients had no focal neurological symptoms or individual pyramidal signs, while the remainder showed mild neurological symptomatology – differences in reflexes, mild pareses, and hypesthesias.

Neuropsychological investigation before surgery showed that all patients had impairments of higher mental functions of similar degrees of severity. The most frequent were memory impairments, seen in 24 of 36 patients. In four of these patients, memory defects were reminiscent of Korsakov's syndrome, while the remainder showed modality-non-specific memory impairments on the background of correct orientation and appropriate insight. These characteristics of the amnesia syndrome completely reflected the nature and direction of the extent of the hematoma following hemorrhage (intraventricular, hemispheric) and were supported by brain CT scan results.

Before surgery, 10 patients showed lack of insight into their condition and, during investigations, showed decreased control over their own errors; mood tended to be elevated.

Impairments of spatial functions were seen in six patients before surgery. The malformations in these patients were in different parts of the corpus callosum, generally in its left half (this being very interesting!), sometimes with minor extension to the left cingulate gyrus. Impairments consisted of inadequate postural praxis, with various extents of impaired ability to copy, defects in the "clock" test, errors of the spatial type seen in "tracking" (in assessments of visual memory), and fragmentation of visual perception. All such disturbances had the features of right hemisphere lesions [16]: for example, in copying a house, patients were unable to reproduce the third dimension; errors in arranging the hands and showing the time on a "clock" amounted to around 5 min. It is important to emphasize that signs of left-handedness were present in only two of these six patients, the rest being right-handed. Figure 1 shows examples of pre-operative copying by patient R. with an AVM and post-hemorrhagic changes in the anterior parts of the corpus callosum. An interesting characteristic of this observation is the development of impairments in optical-spatial activity of the right-hemisphere type in a patient with post-hemorrhagic changes of the anterior (but not the posterior) parts of the corpus callosum without accompanying lesions to the cerebral hemispheres.

The specific symptomatology of partial "split brain" was seen before surgery in 12 patients. Brain CT scans or intraoperative observations in these patients showed post-hemorrhagic changes in the corpus callosum itself. Of these patients, four had AVM in the right parts of the corpus callosum and eight in the left. All 12 patients had different combinations of unilateral agnosia in different modalities (motor, tactile, visual) and impairments of transferring posture from one side to the other.

Agnosia in the tactile and visual spheres, apart from one case, was left-sided. Agnosia of the right half of the space was seen in only one patient – an unretrained left-hander with malformations of the posterior parts of the corpus callosum with extension to involve the left cingulate gyrus. This patient also had clear signs of optical-spatial disturbance, corresponding to those seen in right-handed patients with right-hemisphere lesions.

Agnosia of the left hand in the reciprocal coordination test was seen before surgery in four patients. It is important to note that AVM in two of these were located in the posterior parts of the corpus callosum.

Mild bilateral impairments of the transfer of tactile information (impairments of transfer of hand posture) were seen before surgery in three patients with malformations located in the intermediate and posterior parts of the corpus callosum.

AVM were excised from the corpus callosum in 29 patients. In most (26 cases), AVM were removed by a direct interhemisphere approach. After surgery, 12 patients showed mild increases in focal neurological symptomatology associated with partial extension of malformations to the cerebral hemisphere.

Neuropsychological investigation after surgery showed that the dynamics of symptoms depended on which part of the corpus callosum was subject to surgery, i.e., in most cases, symptoms of partial lesioning of the corpus callosum were modality-specific. Increases in neuropsychological symptomatology were seen in only 17 of the 29 patients. There were no increases in defects of higher mental functions in cases of surgery performed on post-hemorrhage brain changes with severe pre-operative functional losses (for example, memory or Korsakov's syndrome).

After surgery on the anterior parts of the corpus callosum, three of six patients showed worsening of frontal dysfunction, with increased disinhibition, lack of insight, and impulsivity, in combination with inertness, decreased motivation to take part in the studies, and degradation of memory with loss of the selectivity of traces. The malformations had different locations in these three patients (midline, partially extending to the left or right frontal lobe), and emotional disturbances were characteristic of right-lobe dysfunction. Particularly clear impairments were seen in the patient with malformations extending to the right frontal lobe (there were even elements of "frontal behavior"). In other words, combination with the lesion of the corpus callosum apparently worsened the dysfunction of the small lesion of part of the hemisphere.

It should be noted that disturbances to the reciprocal coordination, despite expectation, were not seen after removal of AVM from the anterior parts of the corpus callosum.

After removal of malformations of the intermediate parts of the corpus callosum, increases in neuropsychological symptomatology were seen in four of seven patients. Two of these demonstrated incomplete Korsakov syndrome (without confabulation). In these patients, malformations were located predominantly in the left parts of the corpus callosum but extended partially to the mediobasal parts of the frontal lobe. Limited damage to the latter, combined with damage to the corpus callosum, determined the clinical features of damage to these parts of the frontal lobe.

In a further three patients, removal of malformations from the intermediate parts of the corpus callosum was followed by the appearance of "split brain" symptoms – dyscopia or dysgraphia. We emphasize that the dyscopia and dysgraphia, previously described as a combined syndrome, were seen separately in the present studies. Malformations in these patients were located either in the left parts of the corpus callosum or the midline.

The clearest and most combined manifestations were seen after removal of AVM from the posterior parts of the corpus callosum. Of 17 patients, 10 showed increases in neuropsychological symptoms were seen after surgery.

Of these 10 patients, nine ignored the left edge of the visual field after removal of malformations from the posterior parts of the corpus callosum, this sometimes occurring in combination with tactile ignoring of the left hand. We have previously presented detailed descriptions of the ignoring phenomenon in patients with AVM of the corpus callosum [4].

Five patients, from whom malformations were removed from the posterior parts of the corpus callosum with extension to the left cingulate gyrus and the parietal lobe, showed multiple post-operative "split brain" symptoms. The syndrome demonstrated by these patients has not been described in the literature: right-sided hemihypesthesia or hemianopsia was combined with left-sided ignoring. Thus, damage to the corpus callosum demonstrated the consistency of the phe-

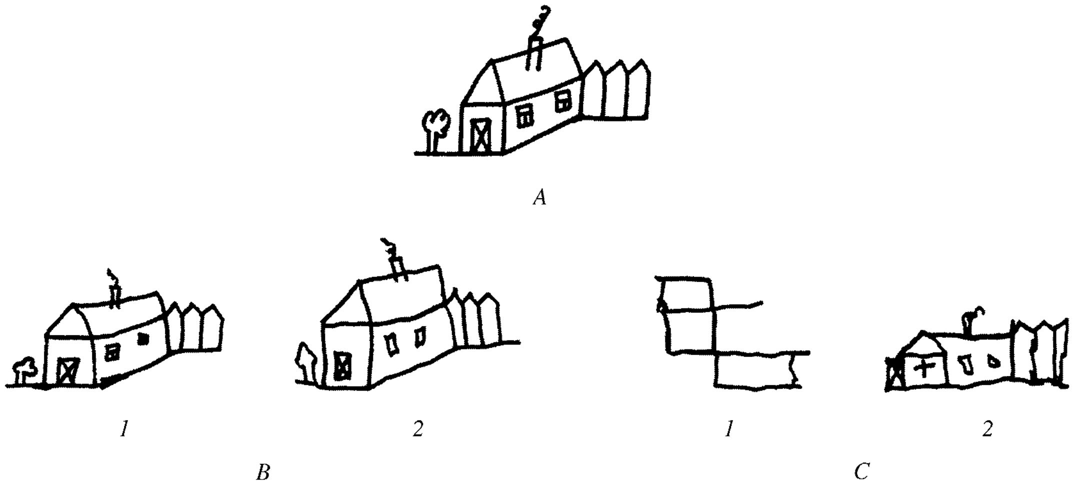

Fig. 2. Copying by patient M. *A*) Image; *B*) before surgery; *C*) seven days after surgery. *1*) Copying with the right hand (dyscopia); *2*) with the left hand. Writing with both hands was preserved.

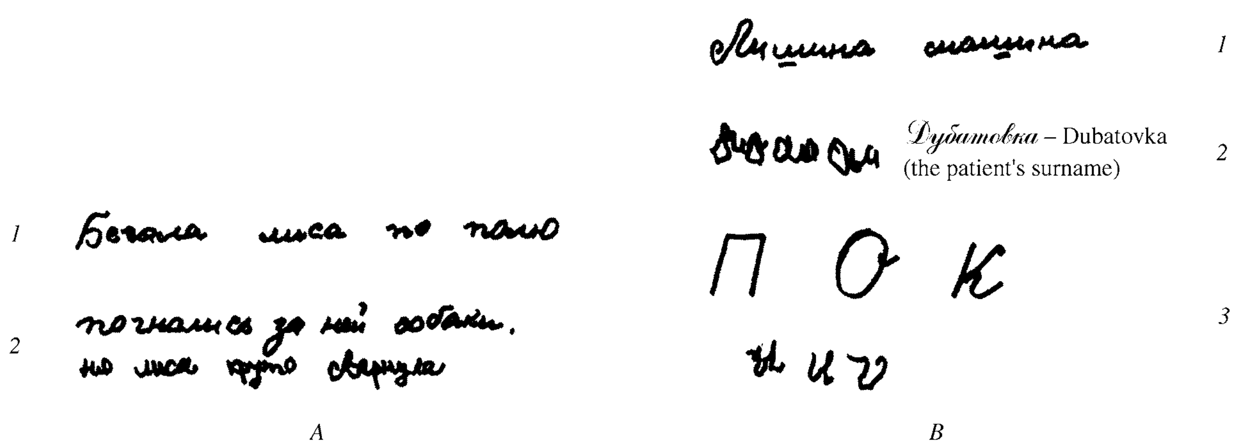

Fig. 3. Samples of the handwriting of patient D. *A*) Before surgery; *B*) three weeks after surgery. *1*) With the right hand; *2*) with the left hand – writing of the patients surname (dysgraphia); *3*) writing of individual letters with the left hand. Copying with both hands was preserved.

nomenon of unilateral right-sided ignoring and its autonomy relative to the primary sensory disorders. The combination of these latter features with ignoring is an obligate sign for lesions of the right hemisphere. Of these five patients, two were characterized by the sensation of having a "foreign" left hand, and one simultaneously had the sensation that he had a "third hand." This patient, the only of those operated for AVM of the posterior parts of the corpus callosum, showed Korsakov syndrome with active confabulations.

Dyscopia and dysgraphia were present in three patients of this group (combined lesions of the corps and the cingulate gyrus). It is important to note that dyscopia (in one patient) and dysgraphia (in two patients) were seen in isolation from each other (Figs. 2 and 3).

Only one case showed elements of tactile anomia, when the patient had difficulty naming a series of objects placed in the left hand, though these objects could then be found by touch with the left hand. This symptom was combined with agraphia of the left hand in this patient.

Increases in spatial impairments after surgery to the posterior parts of the corpus callosum were seen in three patients. Two of these underwent removal of AVM of the right parts of the corpus callosum with extension to the right cingulate gyrus and precuneus. It was difficult to avoid associating the spatial errors in these patients with direct damage to the right hemisphere. However, the mild spatial impairment in the third patient appeared after removal of a malformation of the posterior parts of the corpus callosum, located virtually on the midline. Summarizing the data presented here, it appears that partial damage to the corpus callosum (post-hemorrhagic and post-operative) in patients with AVM affecting these structures is accompanied by various symptoms due to disconnection of the functioning of the two hemispheres of the brain. This has also been indicated by other authors [15, 17, 18]. Symptoms of local damage to the corpus callosum were reported to be modality-specific – defects related to the anterior, intermediate, and posterior parts.

However, our patients and the symptomatology noted in them had their own characteristics as compared both with patients subjected to callesiotomy and those with those described by patients with AVM. The patients studied here displayed signs of partial lesions to the corpus callosum, which in some cases extended to the cingulate gyrus. As a result, the "split brain" symptoms were usually not numerous (and were sometimes singular) in a given patient. When AVM extended from the intermediate and posterior parts of the corpus callosum to the cingulate gyrus, dyscopia and dysgraphia could occur separately, a feature that we were unable to find previously referenced in the literature.

Overall, it seems that damage to different parts of the corpus callosum induced individual symptomatology – with clinical support for the modality-specific transfer of information by different parts of this formation. However, the appearance of motor ignoring of the left hand, as well as impairments of posture, dyscopia and dysgraphia, and tactile ignoring was noted in patients with damage to the intermediate and posterior parts of the corpus callosum. This may be an indication that the corpus callosum contains a heterotypic bundle of fibers connecting different lobes of the brain [14], such as different parts of the parietal and occipital lobes. In other words, the symptoms of local damage to the corpus callosum may be relatively modality-specific. This conclusion is in good agreement with data obtained by Eliassen et al [22], who observed impairment of simultaneous utilization of both hands (spontaneous and in response to a visual stimulus) after both anterior and posterior commissurotomy.

After removal of AVM from the anterior parts of the corpus callosum, we did not detect impairments of reciprocal coordination, although bimanual conflict was generally seen in patients after commissurotomy [21]. There may be two explanations for this. The patients studied here had more local damage to the anterior parts of the corpus callosum. In addition, we did not address (unlike Eliassen et al.) the time characteristics of hand interactions.

The nature of the memory impairments in patients with damage to the corpus callosum are less well studied. Many experiments have demonstrated the role of the corpus callosum and other commissures in transferring conditioned reflexes to the symmetrical half of the body [1, 2, 13]. Investigators have tried to answer the question of whether the corpus callosum is involved in transmitting unprocessed information or formed engrams from the "trained" hemisphere to the "untrained." Simernitskaya and Rurua [18] described impairments in the reproduction from memory of letter stimuli with the left hand and non-speech stimuli with the right in patients with local damage to different parts of the corpus callosum. That is, the existence of functional hemispheric asymmetry in the spheres not only of perception, but also memory, was demonstrated. Zaidel and Sperry found decreases in various measures of memory in patients subjected to commissurotomy [31]. These studies used standard presentation of verbal and non-verbal material (and not in one hemisphere).

Before surgery, memory impairments were the most frequent defects in patients with AVM. However, all patients suffered hemorrhages, and it was difficult to link memory defects with lesions of the corpus callosum itself. After removal of malformations, memory was impaired in five patients. After removal of malformations from the anterior parts of the corpus callosum, two patients (one with a lesion on the midline without extension to hemisphere structures) showed marked worsening of frontal lobe dysfunction. At first sight, patients appeared to have impairment of motivation, inconsistency of planning, and lack of insight. On this background, there was significant impairment to memory, also of the "fontal" type. A further three patients with removal of malformations from the intermediate and posterior parts of the corpus callosum with extension to the mediobasal parts of the brain and cingulate gyrus developed Korsakov syndrome, in one case even with classical confabulations; all three patients showed "split brain" symptoms. In other words, memory disturbances even in patients with isolated lesions to the corpus callosum can correspond to mnestic defects characteristic of damage to those parts of the brain which the lesions disconnect (the frontal lobes play an enormous role in memory processes), or can depend on accompanying damage to neighboring brain structures (for example, the cingulate gyrus). As we have demonstrated previously [3], damage to the cingulate gyrus leads to memory defects similar to those seen in frontal lobe damage. As long ago as 1961, Sperry [29] drew attention to the fact that the symptoms after transection of the corpus callosum involve a large contribution from combined damage to the cingulute gyri. Bogen [21] showed that simultaneous damage to any lobe of the brain and the corpus callosum in animals leads to the development of a picture of bilateral damage to these lobes. We observed this phenomenon in our patients with damage to the cingulate gyri: Korsakov syndrome was seen only in cases in which the focus of damage also affected the corpus callosum (i.e., the limbic system of the two hemispheres was affected). Removal of a small malformation from the medial parts of the frontal lobe with extension to the corpus callosum resulted in clear frontal lobe dysfunction. These data are in good agreement with clinical descriptions in textbooks where the symptoms of tumors of the corpus callosum include mental problems, apathy, and memory defects, i.e., in essence, profound frontal syndrome, which, when there is damage to the corpus callosum, can occur when damage to the relevant parts of the frontal lobes is minor.

The observation of impairments to the functions of the right hemisphere after removal of malformations of the intermediate parts of the corpus callosum without extension to the hemispheres or when malformations partially extend to the medial parts of the left hemisphere (in right-handed patients) is very important for the development of our further understanding of interhemisphere interactions. Dysfunction of the right hemisphere was manifest in the emotional-volitional sphere (increased mood, decreased insight and motivation to activity), the perceptual sphere (one half of space was ignored), and in the performance of optical-spatial functions (copying impairments, errors in the "clock" test). We have previously demonstrated that the right hemisphere has to interact with the left (and that the corpus callosum therefore needs to be intact) for conscious perception of the left half of space (in right-handers) in the phenomenon of ignoring [5]. However, newly obtained data on the syndromes resulting from damage to the corpus callosum showed that disruption of connections (even incompletely!) also impairs right hemisphere function, i.e., those regarded as dominant (emotions, perception, spatial functions). Thus, the right hemisphere can only perform its functions completely when it is tightly linked with the left. It is possible that the left hemisphere, the "conscious" hemisphere, supports the functions of the right hemisphere at the "output." At the same time, we found no signs of left-hemisphere dysfunction in conditions of damage to the corpus callosum – the left hemisphere would thus appear to more autonomous in performing its functions.

These observations are not random. The anatomical-functional features of the hemispheres assist in understanding them. Thus, the right hemisphere is more "diffuse" in terms of the distribution of its functions and it performs simultaneous analysis of stimuli, these characteristics being supported by the structure of its neuronal connections. The left hemisphere has a more "local" organization and is "specialized" to successive actions [7, 28]. Thus, the more "diffuse" organization of the right hemisphere has the effect that it responds to any stimulus, even speech stimuli, more quickly and, thus, earlier [10]. The left hemisphere is activated after this and performs the slower semantic analysis and synthesis. The author believes that the arrival of an individual signal initially in the right hemisphere and then in the left is more "physiological" than the opposite direction of stimulus movement. Heilman and Van Den Abell [27] showed that in healthy volunteers, the right parietal lobe reacts with virtually identical intensity to visual stimuli presented to both the left and right fields of vision. It becomes clear that the right hemisphere integrates stimuli from both sides of space, this with the close involvement of the corpus callosum. Data showing that the right hemisphere is not only the first to respond to any individual stimulus now become very interesting. Krotkova et al. [11] showed that if learning of simple movement acts starts with the left limbs, then the activity will be more successful. In another study, using the evoked potentials method, Danilov et al. [8] recorded the level of pathological activity in the left hemisphere in patients with right-sided strokes and corresponding motor lesions in the left limbs. Consequently, in the damaged state, the right hemisphere sent its spikes to the left and formed a tight connection via the corpus callosum.

Summarizing the our own and published data leads to the following conclusions.

The symptoms of partial lesions to the corpus callosum are modality-specific, but only relatively. The symptoms of dyscopia and dysgraphia can occur in isolation from each other. Combined damage of the medial part of the brain (cingulate gyri, frontal lobes) and the corpus callosum significantly worsens the dysfunction people these medial brain structures. Damage to the anterior parts of the corpus callosum resulted in symptoms of frontal lobe lesions.

Damage to the corpus callosum led to dysfunction of the right hemisphere affecting the sphere of emotions, perception, and spatial activity. The right hemisphere has very close functional connections with the left, and even the performance of functions in which the left hemisphere plays the leading role can be impaired by damage to the corpus callosum.

The right hemisphere integrates spikes from both sides of space and is the first to be involved in activity, performing its initial stages. It is possible that this synthetic activity of the right hemisphere, with tight connections with the "conscious" left hemisphere, is needed for the formation of an overall concept regarding both individual objects and certain types of activity. Better performance of activity in conditions of primary activation of the right hemisphere may also be due to the accompanying obligate activation of the left hemisphere. From this point of view, the right hemisphere can be said, with some arbitrariness, to be the dominant hemisphere, rather than the left.

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