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Neuropsychological Assessment of the Transcallosal Approach

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Summary. The long-term consequences of partial callosal lesions were examined in 7 neurosurgically treated patients. Detailed clinical and neuropsychological assessment of the interhemispheric transfer (multimodal sensory and motor tasks) as well as memory and attention tests were used. The results revealed some disconnection symptoms with minor clinical significance, which could not be attributed to particular sites of the corpus callosum, except the splenium. It is questionable whether the reported memory and attention impairments are caused by the callosal lesion or by extracallosal pathology. The results indicate that the transcallosal approach is a safe and feasible alternative in the management of pathological midline processes in the brain.

Key words: Partial callosal lesion – Interhemispheric transfer – Motor coordination – Memory – Attention – Dream recall – Splenium

Introduction

There are various surgical approaches to supratentorial intraventricular lesions such as colloid cysts, ependymomas, craniopharyngeomas, and angiomas [1]. The classical approach to the third and lateral ventricle is the frontal transcortical approach [2]. The transcortical approaches to the trigonum are through the second temporal gyrus [3], through the occipital lobe [4], or through the posterior parietal lobe [5, 6]. Another approach is the interhemispheric path through the corpus callosum, as first described by Dandy in 1921 [7]. Since the development of microsurgical techniques, the transcallosal approach to midline processes has become more and more popular [8–17], although, its drawbacks have kept it from becoming widely accepted. Patients in whom the corpus callosum has been completely severed show severe impairment of crossed integration between visual hemifields, hands, and speech content [18]. Behavioral abnormalities have also been found in patients with more limited interruptions of these structures, which are caused either by a pathological process [19] or by surgery [20]. Other symptoms reported after partial callosal section are alexia without agraphia [11], mutism [21], unilateral agraphia [22], and short-term memory deficits [12, 23].

In contrast to these reports, other authors found no typical disconnection symptoms among patients with partial callosal lesions [24–26]. Some observed only slight disturbances of tactile transfer with no disturbance of visual, acoustic, or olfactory transfer [27]. Other authors favored the transcallosal approach, but concentrated on the surgical technique without giving details of the neuropsychological consequences [28]. In view of these contradictory reports, it is difficult for neurosurgeons to decide on the transcallosal or on another approach. For transcallosal surgery to be recommended, its safety in terms of long-term functional capacities must be established. In our study, therefore, we included a wide range of neuropsychological assessments, questionnaires on the patients' own estimation and that of their close relatives as well as detailed neurological examinations.

Materials and Methods

Patients

Seven patients participated in the study. All of the investigations were performed in several sessions during a 1-week postoperative stay in hospital. In all 7 patients, the callosal lesion was due to the surgical procedure. The individual approach to

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the midline structures through the corpus callosum was chosen after preoperative angiography and computerized tomography (CT) [1, 14, 15, 30, 31]. The mean age of the patients was 31.1 ± 15.9 years (range 11–68 years). The investigations took place after an average of 20.1 months after the operation, the longest interval was 2 years and 10 months (patient no. 3). Only patient no. 5 had to be examined as early as 8 weeks after surgery. The 7 patients were only investigated postoperatively, as many of them had been in a very uncomfortable state preoperatively and had therefore been unable to cooperate in any difficult tasks. Some had even lost consciousness.

Case Histories

Patient no. 1: This 10.5-year-old boy had an arteriovenous angioma of the genu corporis callosi, which hemorrhaged on October 5, 1980. Surgery was performed on October 24, 1980. The corpus callosum was dissected 3 cm from the genu in the posterior direction about 5 mm along the midline, and the angioma was removed. He recovered from surgery with no complications and returned to school after 8 weeks. The patient reported no personality or behavior changes, and in school there was no evidence of performance deficiency, which his mother confirmed in a detailed interview. The operation was given a positive rating, as the boy was now more alert and cheerful than before. Upon being asked, he clearly pointed out that he could not recall his dreams as well as before surgery and that his dreams primarily contained concrete facts from the previous day or from television. Neurological examination revealed no disturbances, apart from a slight supporting reaction of the left foot [32]. Postoperative CT showed clip artifacts and normal ventricular configuration. The patient was treated with Zentropil. An EEG displayed paroxysmal dysrhythmia with accentuation in the right centrotemporal region.

Patient no. 2: This 65-year-old woman suffered from recurring subarachnoid hemorrhages. She was comatose upon admission to hospital on October 1, 1978. On October 11, 1978, a left occipital ventriculoauricular shunt was put in. Arteriography revealed an arteriovenous angioma in the region of the genu and middle portion of the corpus callosum. The patient regained consciousness after the shunting procedure, but she had Korsakoff's syndrome. On October 17, 1978, the angioma in the anterior and middle third of the corpus callosum was excised. The patient recovered slowly after the operation and the Korsakoff's syndrome disappeared after 6 months. No neurological abnormalities were observed.

In our control investigation (April 1981), the patient reported subjectively that she felt she had improved after the operation. She no longer complained of memory disturbances. Her husband described her as being harder to get along with but essentially unchanged. Neurological examination revealed a slight right-sided hypacusis and amblyopia, a slight bilateral reduction of bathyesthesia, and mildly impaired bimanual coordination. The patient was very cooperative and her orientation was good. Clip artifacts and normal ventricular configuration were seen on CT. An EEG showed paroxysmal dysrhythmia with focal accentuation in the left temporal region.

Patient no. 3: This 26-year-old woman underwent surgery on July 18, 1979 after 10 years of epileptic seizures that occurred with increasing frequency (10 times a day). Arteriography and CT had revealed a lipoma in the anterior third of the corpus callosum. The lipoma was subtotally removed in the anterior and middle parts of the corpus callosum, and the parts in the septum pellucidum and on the left side of the corpus callosum were left. The seizures that had been untreatable prior to surgery did not recur. A slight, left-sided hemiparesis regressed completely, as did a slightly disturbed space orientation. CT revealed unchanged ventricular configuration and no signs of growth of the lipoma parts on the left. Postoperative EEG was unchanged. The patient gave the operation a positive rating: she was now free of seizures, enjoyed life more, and suffered less from fatigue. Her concentration and memory faculties had improved since the operation.

Patient no. 4: This 13-year-old girl had a craniopharyngioma, which had led to weight loss, increasing headaches, seizures accompanied by speech impaired, and weakness of the right arm. Surgery was performed on May 16, 1979 after CT had revealed extension of the tumor into the third ventricle with enlargement of the ventricular system. Transcallosal removal was carried out by transsection of the corpus callosum 12 × 12 mm in the middle third of the corporis callosi. Intraoperatively, the hypothalamus and the tuber cinereum were found to be atrophic. On the 3rd postoperative day, respiratory insufficiency, tachycardia, and electrolytic imbalance were established. On the 8th day after surgery, septic fever set in, which required treatment with antibiotics. After an epidural hematoma over the left hemisphere had been removed, the patient's recovery progressed slowly. At 4 weeks after the operation, she did not speak or show any emotional reactions.

At the time of our investigation in February 1981, the patient was suffering from diabetes insipidus, which was being treated successfully, and narcoleptic seizures; CT showed a slightly dilated ventricular system with no signs of a recurrent tumor or shunt insufficiency (right frontal shunt). There were no focal signs or sharp waves in the EEG. Asked about her dream recall, the patient reported that she had dreamed less often since the operation and that she had more difficulties remembering her dreams than before surgery. She also complained of impaired short-term memory, which was also observed during the investigation. Her biggest complaint, however, was her authoritarian parents, and this depressed her. An interview with the parents partially confirmed this and revealed that the girl was isolated within her family, partly as a result of her illness (memory dysfunction, diabetes insipidus, narcoleptic seizures).

Patient no. 5: This 34-year-old television technician suffered from a colloid cyst in the third ventricle. He had had a 6 year history of headaches. On January 30, 1981, an atrioventricular shunt on the left was inserted, which then had to be removed because of infection. Tumor growth and ventricular enlargement led to surgical removal of the colloid cyst using the transcallosal approach (2 cm dorsally from the genu) on February 9, 1981. For aobut a week after the operation, the patient was mute (aphasic) and apathetic, but remained awake. He now has no recollection of this period of time.

In our investigation in April 1981, 8 weeks after the operation, speech was impaired in all test modalities (visual, acoustic, written, spontaneous speech, various speech examinations). Neurological examination revealed a saccadic pursuit of eye movements with spontaneous nystagmus to the right and upwards. A symmetric accentuation of myotatic reflexes with no paretic signs was interpreted as a residual preoperative brainstem lesion due to increased intracranial pressure. CT showed a small ventricular system with a frontal shunt on the left. EEG revealed pathological focal activity in the right frontotemporal region with no clinical seizures. Spontaneously, the patient did not complain of any disturbances. When asked about his memory, he reported a slight impairment of short-term memory, which he was able to compensate for by writing notes. Dream recall and dream frequency had not changed after the operation (low dream frequency). Autopragmatic amnesia as described by Dimond and co-workers [20] was observed during the investigation. The patient could not remember exactly the tasks and investigations he had performed during the previous 3 h. However, this was the only patient investigated soon after surgery.

Patient no. 6: This 24-year-old technician suffered a subarachnoid hemorrhage on August 18, 1976. Arteriography revealed an angioma in the middle and posterior parts of the corpus callosum. Surgery was performed on October 5, 1976 and November 28, 1978. In the second operation, the angioma was removed radically involving the middle and posterior third of the corpus callosum, the left fornix, the fissura transversa cerebri, and the left pulvinar thalami. Most of the splenium was removed, but some splenial fibers were left uncut. Postoperative arteriography revealed no angioma. Postoperatively, the patient complained of difficulties in eye movement coordination and disturbances in the right visual field. These symptoms regressed completely.

During our investigation in March 1981, the neurological examination showed only a bilateral supporting reaction of the feet [32]. CT revealed the defect of the corpus callosum in the center and the splenium, while the EEG showed no specific change. The patient displayed slight impairment of short-term memory and a tendency to confabulate by telling the same stories over and over again. His only subjective complaint was increased sweating and occasional double images when he looked downward with his head tilted back. Ophthalmological examination revealed complete recovery of the postoperative incomplete homonymic hemianopsia, which meant completely normal findings. There was slight strabismus divergens, which had probably existed since childhood. Further findings included normal stereoscopy, inborn deuter anomalia, and slight left afferent pupillary disturbance. The patient reported no dream recall, as had been the case before surgery. He noted no impairment in carrying out his profession as a technician.

Patient no. 7: This 37-year-old housewife had an arteriovenous angioma of the right praecuneus, posterior part of the right gyrus cinguli, and the splenium corporis callosi. She had complained of migraine since the age of 18. On December 14, 1978, she suffered a subarachnoid hemorrhage. Arteriography revealed a 3 × 20 × 15 mm arteriovenous angioma which was treated surgically by right occipital trepanation on January 18, 1979. The posterior third of the corpus callosum and parts of the right posterior commissural fibers had to be removed. Postoperatively, the patient remained awake and had no speech impairment. She displayed slight upper left quadranopia and impairment of fusional convergence, which was possibly due to the callosal lesion. Her visual memory also seemed impaired. Neurological examination revealed a latent sensomotor hemiparesis on the left with accentuation in the lower limb and with occasional seizures in the left foot. Behavioral changes included depressive reactions, generally reduced performance capacity, and emotional instability. She complained of impaired memory and concentration and was prone to apathy. Her rating of the operation was negative. Her dreaming had changed totally: before surgery she had dreamed frequently and had been able to remember the contents of her dreams. Since the operation she had not been able to remember any of her dreams and was not even sure if she dreamed at all.

During our investigation in March 1981, the patient showed little cooperation, considerable fatigue, and had many complaints. Her short-term memory was severely impaired, she often forgot what she was supposed to do while she was performing a task. She claimed she was unable to write her curriculum vitae and did not cooperate in spontaneous drawing. Ophthalmological examination revealed normal visual acuity (as in patient no. 6), upper left quadranopia was more severe than on the right. There was no disturbance of the central visual field. Color differentiation and naming was normal with both eyes. Routine examination showed stereopsy to be unimpaired, though it appeared to be impossible for the central 3°. Pupillary reactions were normal. CT showed normal ventricular configuration. An EEG revealed slight focal accentuation of the alpha rhythm and focal dysrhythmia in the right temporoparietal-occipital region.

Controls

The patients above were compared with 10 right-handed and 5 left-handed control patients (8 men, 7 women, mean age 31.1 ± 5.07 years). For the memory and attention performance tests another control group matching with respect to age, level of education, and professional qualification was selected.

These 10 control patients had no cerebral diseases and no expected restriction of their memory or attention performance.

Methods

The large battery of methods used in this investigation can be classified in 3 groups: (1) clinical examination, (2) examination of handedness and multimodal interhemispheric transfer, and (3) memory and attention tests.

1. Clinical Examination

All of the patients underwent a detailed neurological examination, pre- and postoperative CT, EEG while awake and asleep, an ophthalmological examination (a highly sophisticated test used in case no. 6 which included a color vision examination), and a hearing examination. In addition, interviews were carried out with the patient and close relatives, in which the following were discussed: general postoperative changes, sleep, dreaming and dream recall, capacity of visual perception, short-term memory, autopragmatic amnesia, i.e., patient was asked to talk about what he had done during the previous 3 h [20], concentration, learning ability, emotional and sexual aspects, profession, perspectives for the future, subjective rating of the operation.

2. Handedness

Handedness was tested to determine the possible localization of the speech area and a possible change in handedness [20]. The following procedures were used: Edinburgh Handedness Inventory [33]; a tapping test, which involved tapping on a key as quickly as possible with alternating hands; Hand-Dominanz-Test [34], which comprised various tracing tasks to be done with alternating hands.

3. Interhemispheric Transfer

These tests were intended to establish whether a general split-brain syndrome [18, 19, 35] or a specific disconnection existed, based on the supposition that the different parts of the corpus callosum have specialized functions in modality transfer [36]. The following procedures were applied: Unilateral motor functions – tested with each hand separately: copying a written test, taking dictation, writing the alphabet spontaneously, drawing 3-dimensional objects; bilateral motor functions – patients asked if able to type, play a musical instrument; stringing beads bimanually with eyes opened and closed [10]; drawing symmetrical figures (circles, squares, rectangles) in the air with both arms simultaneously without visual control [18, 35]; somesthetic transfer: touching different segments of the fingers of the left and the right hand, which was copied by the patient with the thumb of the other hand after correct ipsilateral performance [10, 18, 35]; touching different parts of the body and subsequent imitation on the other side with the opposite hand [20]; imitating hand postures: examiner formed the patient's hand, patient imitated with the other hand [18, 35]; tactile transfer: graphesthesia; comparison of the texture of clothes and of the dimension and weight of spheres with both hands and without visual control; reproduction of nonidentifiable forms with 6 straight sides engraved in a wooden plate (touching them with one hand and drawing under visual control with the other); verbal identification of objects touched with the right or the left hand [27]; olfactory transfer: smelling 4 different scents (vanilla, peppermint, codliver oil, coffee) either with the left or the right nostril [27, 35]; visual transfer: naming and identifying objects and words presented in the left or the right visual field (LVF and RVF) with a tachistoscope [18, 35]; imitating hand postures presented in the LVF or RVF with a tachistoscope; identifying objects presented simultaneously in the LVF and RVF with a tachistoscope – optic rivalry [37]; acoustic transfer: dichotic listening procedure: well-known noises, well-known melodies played on the piano, and stories told by a male or female voice on both ears separately while the patient had to retell the story told into one ear [38] (shadowing); visuomotor transfer: reaction times of the right and left hands measured for visual stimuli presented at random in the LVF or RVF; reactions of crossed and uncrossed pathways were compared.

Memory and Attention Tests

Memory: based on the memory disturbances expected [20, 23, 26], the following procedures were used: Wechsler Memory Scale [39] and Wechsler Intelligence Scale (German version) [40] to determine the MQ/IQ ratio; recognizing geometric shapes [41]; matching names with faces [35, 42]; examination of delayed recall after 1.5 h for Wechsler Memory Scale IV, and VII, recognition of geometric shapes and matching names with faces; short-term memory of words and pictures with a signal detection task as an interpolated task; test for memory of rhythm (patient repeats a sequence of beats); test of autopragmatic amnesia; score of compiled memory tests, i.e., the ranking of the patients and controls were summed up for each person for the following tests: Wechsler Memory Scale, recognition of geometric shapes, matching names with faces, short-term memory tasks. There were 3 scores: for all memory tests, for verbal tests, and for visual tests.

Attention: according to the contrasting reports on attention [43, 44] the following procedures were used: simple reaction time for the LVF or RVF; a letter discrimination task, in which 1 out of 8 letters was chosen at random and presented in the LVF or RVF, patient responded by pressing corresponding key on a keyboard; attention test d2 (attention strain test [45]); attention test (KLT) [46]; Trail Making Test (TMT) form A and B [47]; test for sustained attention of LVF and RVF according to reaction time (letters in pseudorandom order presented to the LVF and RVF with letters B, E, or U as targets, duration: 20 min); scores of compiled attention tests tallied for each person for all procedures.

Statistical Method

The differences between the patients and the controls in memory and attention performance were tested statistically. Analysis of variance was used for the tests of simple reaction time, letter discrimination, and sustained attention (vigilance). Otherwise, the differences were tested by the Mann-Whitney *U*-test.

Results

1. Clinical Examinations

An overview of the findings of the various clinical examinations is given in the case histories. It should be pointed out that speech disturbances were always transient. The supporting reaction and grasp reflex of the feet was observed in 2 patients (1 and 6) with different localizations of the callosal lesion. This reflex is reported to be the result of the commissurotomy [32] and not of extracallosal damage. The changes in EEG mainly reflected extracallosal lesions. The sleep derivations of the EEG showed no difference in sleep stages between the two hemispheres, nor any change in the profile of sleep stages. Although 4 patients complained about restricted dream recall, no corresponding reduction in the rapid eye movement stage was observed (18%–22%). Only 1 patient (no. 7) gave the effect of the operation a clearly negative rating.

2. Examination of Handedness and Interhemispheric Transfer

Handedness: all of the patients were right-handed, except for no. 6, who had been trained at an early age to switch to the right hand. No effect of the operation on handedness was shown in any of the tests. With the exception of patients no. 6, it can be assumed that all the patients had their speech area in the left hemisphere.

Interhemispheric transfer: Unilateral motor functions: copying a written text and taking dictation with either hand posed no difficulties for any of the patients. Patients 6 and 7 had problems writing the alphabet spontaneously, as both were unable to produce some letters, though they could identify them correctly. Patients 6 and 7 were not able to make 3-dimensional drawings with the right hand, a deficiency which has been attributed to complete commissurotomy [18].

Table 1. Results of tests for somesthetic transfer

Patient no.	Finger touch	Hand posture	body touch	Graphes-thesia	Texture	Dimensions	Nonsense forms	Tactile Identification of objects
1	Normal	Normal	Normal	Normal	1 Fault	No marked differences to normal controls	Impaired	Normal
2	Impaired	Left to right impaired	Normal	Normal	Normal		Impaired	Normal
3	Impaired	Normal	Normal	Normal	Normal		Normal	Normal
4	Normal	Normal	Normal	Normal	1 Fault		Impaired	Normal
5	Impaired	Left to right impaired	Normal	Normal	Normal		Impaired	Normal
6	Impaired	Impaired	Normal	Normal	Normal		Strongly impaired	Normal
7	Impaired	Impaired	Normal	Impaired	Normal		Strongly impaired	Impaired

However, these patients, along with nos. 1 and 3, also had minor difficulties reproducing 3-dimensional drawings with their left hand.

Bilateral Motor Functions: reduction of motor activity was reported by patient no. 7. She had difficulties with her left hand (slight ideomotor apraxia), and the disability could not be adequately explained by a left-sided subclinical sensory motor weakness. She claimed that while she was typing, her left hand "went away after having made more and more mistakes". A weakness in bilateral motor coordination was observed in 5 patients: the difficulties in making symmetrical figures in the air with both arms was explained for some patients by their left-sided weakness, but not for patients 3 and 6, who did not complain of any such impairment. In contrast, no patient had any difficulties stringing beads without visual control. It is striking that the advantage of visual control was less for the patients than for the controls: with the aid of visual control, the patients strung fewer beads in 2 min than the controls (*t*-test statistically significant – $\alpha = 5\%$).

Somaesthetic and Tactile Transfer: (see Table 1) the results of these tests varied considerably; none of the patients had difficulties locating a touch on one side of the body, nor did they have serious trouble comparing textures and spherical dimensions. Only patient no. 7 showed marked impairment in the test of graphesthesia and tactile identification: she could not identify numbers written on her skin (100% rate of error on the left side, 70% on the right) and she could not name 3 out of 7 objects placed in her left hand.

Considerable difficulties for the majority of patients were observed in the tactile transfer of finger stimulation and the contralateral imitation of hand postures (Table 1). Only patients 1 and 4 had no problems carrying out these two tasks. The other patient were able to perform the tactile transfer finger stimulation correctly as long as stimulus and response were on the same side, but they had a 30%–50% error rate on the opposite side. Contralateral imitation of hand postures was impaired for these patients, except no. 3, who performed the task correctly.

The most difficulties were found in reproducing non-identifiable shapes – touching with one hand and drawing under visual control with the other. Only patient no. 3 was able to do these tasks easily: she produced all 4 shapes correctly, but unknowingly rotated 2 shapes by 90°. Patients 6 and 7 had the most trouble: they made cloud-like shapes. The same patients were unable to reproduce the test shapes ipsilaterally, which indicated that the task is not suited for testing tactile transfer but only for testing tactile shape perception and the mental storage of space and shapes. Patient no. 2 clearly showed the efficiency of a cross-cuing strategy in performing this task: she was able to reproduce all the shapes contralaterally after she had found a verbal code for one. This strategy was also possibly used by patient no. 3, who reproduced all the shapes but rotated 2 shapes without realizing it.

No difficulties were observed in the other transfer tasks. Visual, acoustic, olfactory, and visuomotor (measured by crossed and uncrossed reaction time) transfer was unimpaired, as was the naming or tactile indication of visually presented objects in both visual fields in comparison with the controls.

3. *Memory and Attention Tests*

Memory: The results are summed up in Table 2. Two points with regard to the patients' own reports of memory deficiency are noteworthy: (1) with one ex-

Table 2. Results of the memory tests

Patient no.	Patient's evaluation		Wechsler memory scale: MQ	MQ/IQ ratio	Delayed responses	Recognition of geometric shapes
	Memory in general	Short-term memory				
1	No complaint	Good	105	0.68	Normal	11
2	No complaint	Not changed	110	0.96	Normal	8
3	No complaint	Good	90	0.99	Normal	11
4	General deficit	Strongly impaired	64*	0.74*	Normal	11
5	No complaint	Impaired	97*	0.89*	Reduced*	8
6	No complaint	Good	81*	0.75*	Reduced*	10
7	General deficit	Strongly impaired	80*	0.99	Reduced*	7*
Comparison with controls	Patients (mean value)		93.85 N.S.	0.92 N.S.	N.S.	9.50 N.S.
	Controls (mean value)		105.90	0.99		10.70

Patient no.	Matching with faces (12 items)	Short-term memory		Autopragmatic amnesia	Rhythm memory	Compiled memory scores
		Words (5 × 5 items)	Pictures (5 × 5 items)			
1	7	10	23	No	Good	Normal
2	3*	6*	18	No	Immediate response: good delayed response: bad*	Impaired*
3	9	20	24	No	Good	Normal
4	6	14	22	General deficit	Disturbed*	Impaired*
5	3*	21	19	Marked	Good	Normal
6	7	19	19	Slight	Slight disturbance	Impaired*
7	7	18	15*	General deficit	Immediate response: good delayed response: bad*	Impaired*
Comparison of patients with controls	6.00 S.		20.9 N.S.	N.S.		142.25 S.
	8.00		22.4			110.40

* = reduced performance
S. = statistically significant ($P < 0.05$)
N.S. = statistically not significant

Table 3. Results of attention tests

Patient no.	Patients evaluation of their attention performance	Simple RT for LVF and RVF	Discrimination of letters: RT	d2 (standard = 100)	KLT (standard = 100)	TMT A cut-off = 4)	TMT B cut-off = 4)	Sustained attention in LVF and RVF	Compiled scores[a]
1	Good	Increased*	Normal	100	83*	10	4	Normal	Impaired*
2	No difference	Increased*	Normal	90	83*	4*	1*	Normal	Impaired*
3	Better since operation	Increased*	Normal	88	60*	9*	3*	Normal	Impaired*
4	Much worse since operation	Increased*	Normal	90	90*	10	1*	Normal	impaired*
5	Bad since operation	Normal	Normal	100	80*	10	4	Normal	Impaired*
6	No difference	Normal	Normal	88	85	10	3*	Normal	Impaired*
7	Strongly impaired	Increased*	Normal	92	82*	6*	1*	Impaired*	Impaired*
Comparison with controls		S.	S.	S.	S.S.	S.	S.S.		S.S.

* = reduced performance
S. = statistically significant ($P < 0.05$)
S.S. = strongly significant ($P < 0.01$)
[a] Compiled test scores of Wechsler Memory Scale III, d2, KLT, Trail Making Test (A + B) RT, reaction time; LVF, RVF, left and right visual field

ception (patient 5), it was the patients with extended extracallosal lesions (patients 4 and 7) who reported either an impairment of short-term memory or general memory deficiency; patient no. 5 reported short-term memory impairment only after having been asked specific questions, and (2) memory impairment was observed in patients who did not perceive any difficulties themselves.

The results of each individual patient or of the specific test showed definite inconsistencies. With the exception of 1 and 3, all of the patients manifested reduced performance in single tests, which was not observed among the controls. However, each patient showed another deficiency pattern, and no consistency among the patients was seen in any of the tests. A statistically significant difference between patients and controls was only established in 2 tests: matching names with faces and testing short-term memory of words. A more reliable evaluation of the reduced performance of the commissurotomy patients was given by the compiled memory score. All of the patients (except patient no. 5) showed lower performances than any of the controls.

Attention: The results of the attention test are presented in Table 3. All of the patients showed attention impairment. However, not 1 patient had difficulties in all tasks nor all patients in one certain task, although in all of the tasks there was a statistically significant difference between patients and controls. The same patients who perceived no memory impairment were also unaware of their weakness in attention performance. Attention seemed most reduced in the KLT and TMT B tests: there was not 1 patient who did not show reduced performance in at least one of these two tests. In this study, the KLT was even more discriminating than the TMT B or the TMT (A+B). It is questionable as to whether these results can be attributed to a specific lesion of the corpus callosum, as the TMT is regarded by some authors [47] as an indicator of general brain damage.

Three of the tests (letter discrimination, d2, vigilance) revealed only slight impairment among the patients. Thus the differences between patients and controls were statistically significant in two tests (discriminating letters and the d2 test), meaning that the mean performance of the patients was slightly reduced.

With regard to the vigilance task, the normal performance of patients was remarkable. Some patients (1, 2 and 3) had slow reaction times in comparison with the controls, but the expected vigilance decrease over a period of 20 min was only observed in patient no. 7. In contrast, most of the patients showed a shortening of reaction time during the course of the examination (training effect?), which was not observed among the controls. Patient 7's performance of the vigilance task was considerably reduced, and she had the most trouble in the RVF (she stopped after 15 min).

Noteworthy are the results of the simple reaction time tasks. With the exception of no. 7, who had had complete splenial dissection, the patients with anterior and center trunk lesions of the corpus callosum showed lengthened reaction times for both the RVF and LVF, which was consistent with the increased reaction times measured in the vigilance task for patients 1, 2, 3, and 4 (not shown in Table 3). This was all the more striking, as patient 1 (who was almost unimpaired in all other tasks) showed the same lengthened reaction time. This was the only consistent finding in all of the memory and attention tests. It suggested that lesions of the anterior and middle parts of the corpus callosum might lead to a general slowing down of reactions. There was no clear correlation with other symptoms.

Discussion

With regard to the transfer between the hemispheres, the results of the study can be summed up as follows: on the one hand, there was a wide range of functions showing no deficits at all. This was true for all callosal lesion sites and contradicts the simplified location theory [20, 36, 48]. On the other hand, there were some noticeable difficulties among patients with partial callosal lesions, which, however, were not consistent among all patients and throughout the tests. Impairment of somesthetic transfer, for example, which is manifested in contralateral imitation of finger touching and hand postures, was observed in patients with lesions of very different locations (frontal, midsection, or splenium). Also the transfer of tactilely perceived shapes was markedly impaired in all patients except no. 3. The difficulty in simultaneously drawing symmetrical figures in the air with the arms clearly seemed to be associated with this deficiency in shape perception (Table 1). This disturbance should not be attributed to a disturbance in motor coordination, particularly since there was no evidence of coordination problems when the patients were stringing beads, nor was there any disturbance of visual memory (geometric shapes, words, and pictures: Table 2) to explain these findings. Thus, as an alternative explanation to callosal disconnection, or as a consequence of it, a disturbance of some sort of motor imagination could be assumed to be the common source of the impairments. Another interesting observation was that 2 patients (6 and 7) were unable to draw 3-

dimensional figures with the right hand, and also had difficulties with the left – a disorder that up to now has been primarily found among complete commissurotomy patients [18].

There were considerable differences with regard to the general impairment of the individual patient. Patients 1 and 4 showed only slight impairment. Since both were very young (10.5 and 13 years at time of operation), there is reason to believe that the greater elasticity of the young brain kept damage to a minimum. On the other hand, patients 6 and 7 with lesions of the splenium showed severe impairment. In contrast to other authors [24–26], who showed the absence of disconnection symptoms after partial callosal lesions, we found definite callosal symptoms, though not highly location-specific. There have even been contradictory reports regarding such symptoms after complete commissurotomy [18, 24]. Although we found these symptoms, it should be pointed out that the disconnection symptoms had up to that point gone unnoticed by the patients themselves. The presence and extension of the extracallosal lesions seemed to have more influence on the patients' abilities and disturbances in their daily lives (with the exception of patient 7). Although extracallosal damage has also been mentioned by several authors [11, 25, 49], it is rarely discussed.

These discrepancies might be explained by a lack of refinement of the investigation. Thus, case 9 of Akelaitis's study [24] was re-tested 27 years later by Goldstein and Yoynt [50] and was found to have defects in the transfer of training in manual tasks and in crossed visual-tactile identification, which had not been determined in the first examination. A thorough and meticulous investigation will pick up even slight disturbances of tactile transfer [27], as could be demonstrated among our patients.

Memory disorders were present but were not serious or consistent, except in patient 7. Some authors attribute deficiencies in memory performance to total and partial commissurotomy [20, 23], some do not [16, 26], and others are not sure [12]. Special tests were employed for assumed specific memory deficiencies: difficulties in recalling visual stimuli were reported by Zaidel and Sperry [23] and by Geffen et al. [12]. Springer and Deutsch [42] emphasized the difficulties split-brain patients have in matching names with faces. This task made a clear distinction between our patients and controls, as did the test of short-term memory of words. Although the compiled memory scores are a reliable assessment of the diminished memory performance of commissurotomy patients, the inconsistency of the results must not be overlooked. It should be emphasized that the large battery of tests used in this study made it possible to establish disorders which would not have shown up in any single test, nor in any subjective reports.

With respect to callosal lesions, it was notable that no deficiencies could be established in case 1 in which extracallosal lesions were ruled out. This is not in agreement with Zaidel and Sperry [23], who proposed that the deficiencies of memory, especially short-term memory, could be attributed to the callosal lesion. Also their location theory, i.e., that deficiencies in verbal memory tasks are caused by lesions of the anterior two-thirds of the corpus callosum, are not supported by the present results.

Two aspects should be mentioned here: (1) an impairment, as described by Dimond et al. [20] called autopragmatic amnesia, was observed in a more or less severe form in 4 patients. Whether this disorder can be traced back to the commissurotomy cannot be answered here, as the results were not systematic for all of the patients. However, all the patients with generally reduced memory functions, except no. 5, showed autopragmatic amnesia to some extent. To our knowledge, it has not been established whether or to what extent this disorder also occurs whith memory impairment of other origins. (2) The weakness in the perception of shapes, which was observed in somesthetic tactile transfer, did not appear to be caused by disorders of the visual memory functions, which were only established in a few cases.

According to William and Pennybacker [51], memory disorders are associated with tumors of the third ventricle and can disappear after the tumor has been removed. Geffen et al. [12] emphasized that bilateral lesions of the fornix may produce short-term memory deficiencies and that tumors of the third ventricle may lead to functional fornical lesions or pressure on the nucleus magnocellularis medialis dorsalis thalami. The particular role of the corpus callosum in the disturbance of short-term memory is thus put into question. In patient no. 7, disturbances in blood supply as a result of the arteriovenous angioma in the midline structures might have been responsible for the memory impairment. The less severe memory deficiencies in the other patients could have been effected by the cerebral mass lesion [52], or by the extracallosal lesions. It does not seem very likely that the corpus callosum has a specific memory function, since there was no common pattern of memory disturbances among the patients, nor was there any correlation between whatever disturbance patterns there were and the site of the callosal lesion.

In the section on attention performance (Table 3), all of the patients showed impairment, at least in the compiled scores, although there was inconsistent accentuation in the single tests. The special role of the corpus callosum must be questioned, as attention deficits are often regarded as a general consequence of brain damage. However, two observations should be pointed out: first, there was a marked slowing down of reaction time in all of the patients with lesions of the anterior and middle part of the corpus callosum, and secondly, there were no general deficits in sustained attention, with the exception of patient 7. Difficulties in sustaining attention have been reported in patients with total commissurotomy [43, 44, 53]. Dimond [44] did not observe such disturbances among patients with partial commissurotomy, while Ellenberg and Sperry [54] reported that such patients have difficulties with passive signal detection tests. However, our results of the vigilance tasks corroborate Dimond's [44] view, who stated that in partial callosal lesions, the pattern of vigilance impairment seen in cases of complete commissurotomy is only observed when the splenium is dissected. This was seen in patient 7, who was the only patient with dissection of the splenium, but not in patient 6, who had splenial lesions with sparing of some remnant fibers.

As to aphasia none of our patients displayed any permanent speech impairment. We thus consider the case of mutism reported by Susmann et al. [21] an isolated case. This could have been a depressive or schizophrenic mutism, but the authors gave no clear psychological description to back up this presumption. The transient mutism (lasting only a few weeks), which was observed among some of our patients, might be due to functional disturbances of the supplementary motor area resulting from intraoperative pressure from the spatula.

With regard to location, it is known from the arrangement of the interhemispheric callosal fibers that the frontal lobes are connected via the rostrum and genu corporis callosi, the mid-temoral, posterior-temporal, and parietal lobe fibers pass through the body, and the occpital lobe fibers pass through the splenium. The mesial and anterior portions of the temporal lobes are connected by the anterior commissure. Therefore, specific disturbances of interhemispheric transfer might be expected after disconnection of the corpus callosum. But in our study, no definite relation between the site of the callosal lesion and the specific clinical symptoms could be established, perhaps because it is the extracallosal damage which plays a more important role. In any event, our results do not substantiate the location theory [17, 20, 23, 36, 48–56]. The plasticity of the human brain might offer another possible explanation of why there is no definite relation between site of lesion and disorder [57]. It could be assumed that the function of the dissected callosal fibers could be compensated for (after an early acute disconnection syndrome) by other parts of the corpus callosum via associated intrahemispheric connections. Accordingly, some authors have postulated visual transfer through the anterior commissure [26, 27], while others consider the splenium responsible for a multimodality transfer [25]. These reports and our results are not entirely consistent with the interpretation of Gazzaniga et al. [58]: he claims that the transfer of simple sensory information appears to depend on the integrity of those sections of the corpus callosum that are responsible for each sensory modality, while more highly processed information can be transferred via a number of pathways.

But it should be stressed that the complete dissection of the splenium leads to considerable emotional and attention impairment, as was seen in patient 7. She displayed the worst performance of all the patients in all areas (Table 1–3). Perhaps her poor memory performance has to be seen in connection with the attention problems mentioned. The hypothesis of the special role of the anterior two-thirds of the corpus callosum in memory functions does not hold true in this patient with intact anterior commissures. Volpe et al. [55] gave a different significance to the role of the splenium in their description of 2 patients with initial division of the splenium and of the posterior 3 cm of the corpus callosum, who displayed marked impairment of the coordinate movements of the hand on the same side as the hemisphere receiving the command. But similar symptoms were not established when only a few fibers of the splenium were preserved, as was the case in patient 6. This emphasizes the fact that even small commissural remnants left intact – either intentionally or unintentionally – still maintain their functional capacity.

However, the present study provides arguments in favor of the transcallosal approach [29]. Our findings of slight but definite disconnection symptoms contradict reports of the absence of neurological, neuropsychological, or behavioral abnormalities following partial callosal lesions [6, 25, 26], but they partly correlate with other reports [10, 12, 20, 23]. Since patients with agenesis of the corpus callosum have been found to have a restricted integrative capacity for visual, fine motor, and tactile performance [59], it would be surprising if patients with partial surgical lesions of the corpus callosum did not have similar deficiencies. However, some postoperative disconnection symptoms usually disappear after a few weeks and only a few remain for a longer period of time [10, 12, 20, 57, 60]. Only the longer lasting disturbances are relevant for the decision as to whether to use the transcallosal approach or not. Although the disconnection symptoms described above were detected in the tests, only patient 7 had subjective complaints about symptoms that were very probably related to the callosal lesion. In the other 6 patients, not the callosal lesion but the extracallosal pathology seemed to play the more important role. It should be pointed out that the transcortical approach also involves cutting commissural fibers, which causes the disconnection of cortical areas. This phenomenon is not confined to the callosal region [29]. However, disabling seizures following transcortical surgery have often been observed [61], and some authors report that this is to be expected particularly in young patients [10]. None of our patients – in spite of abnormalities in EEG – developed epilepsy after callosal surgery which is a further argument in favor of the transcallosal approach.

In conclusion, it should be emphasized that the disconnection symptoms described do not lead to any impairments that affect everyday life unless the splenium is completely cut. Marked acute or chronic disconnection syndromes do not occur when the rostrum, genu, and anterior half of the body of the callosum are divided. If more space is needed, the surgeon need not fear to make longer incisions in this structure. Basal cysts can be punktured by transcallosal stereotaxy instead of by the classical transcortical method. The most severe symptoms are caused by the extracallosal pathology. According to Bogen [62], only the posterior region of the splenium should be treated with caution and, whenever possible, not be dissected completely. If these guidelines are adhered to, the transcallosal microsurgical approach to midline structures seems preferable to the classical transcortical approach, which also interrupts commissural fibers and leads to cortical damage and a higher risk of postoperative epilepsy.

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