Original

The Relationship between Frontal and Temporal Lobe Lesions in Traumatic Brain Injury and Procedural Memory

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Abstract

We examined the correlation between the location of chronic phase brain damage identified by a head MRI and the procedural memory test results in patients who have sustained a traumatic brain injury (TBI).

Subjects were 27 patients with TBI, who completed all of three procedural memory tasks (mirror-reading, mirror-drawing, and Tower of Toronto). Using a head MRI, the presence or absence of lesions in the frontal lobe and the temporal lobe were determined. To evaluate declarative memory, we implemented the Wechsler Memory Scale-Rivesed (WMS-R), Rivermead Behavioral Memory Test (RBMT), and Rey-Osterrieth Complex Figure Test (3-minute delayed recall). All three of procedural memory tasks were repeated 3 times a day for 3 consecutive days. The rate of improvement (%) of the procedural memory task was determined as {(average of the results on the first day − average of the results on the third day)/average of the results on the first day} × 100. We obtained the rate of improvement for each of the three tasks. The patients were divided according to the existence of frontal and temporal lobe lesions in brain MRI, and then rates of improvement were compared by the existence of frontal or temporal lesion using the Mann-Whitney test.

In result, the average value of the declarative memory test results was within the range of disorders for all items. On the procedural memory tasks, the rate of improvement did not significantly decrease by the presence of frontal or temporal lobe lesion.

It is believed that the basal ganglia and the cerebellum are significantly involved in procedural memory. Also in TBI patients, the procedural memory tends to be retained. Our results suggest that frontal and temporal lobe lesions, which are frequently found in traumatic brain injury, are not likely to be related to procedural memory.

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—Key words—

traumatic brain injury, procedural memory, brain contusion

I. Introduction

Procedural memory, a type of nondeclarative memory, functions by learning and acquiring regularity in operations through repeated experience and practice of skills. It is believed that it is independent from memories of, for example, results from individual motion or operation[1] and that it instead refers to a memory of performance and actions that cannot be expressed in words, wherein the speed of reaching a certain goal increases through repetition, and the pattern of movement toward reaching the goal becomes increasingly more sophisticated. Some cases are known whereby the declarative memory becomes disordered, while procedural memory is maintained. In patients who suffer from amnesia[1)~3)] or Alzheimer's disease[4)~7)], which is a typical form of cortical dementia, cases have been reported in which a separate procedural memory is individually maintained according to sensory, motor, and cognitive criteria. In patients who have sustained a traumatic brain injury (hereinafter referred to as TBI patients), which typically manifests in memory impairment, it is believed that procedural memory tends to be retained[8)~10)]. To promote the cognitive rehabilitation of TBI patients, it is important to utilize residual procedural memory. To the extent of our knowledge, until now, there have not been any reports on the location of brain damage and procedural memory in TBI patients. In this study, we therefore examined the correlation between the location of chronic phase brain damage identified by a head MRI and the procedural memory test results.

II. Subjects and Method

Subjects

From among the TBI patients who were hospitalized at our clinic for an evaluation of higher brain functions from February 2002 to June 2006, we selected 27 individuals who were able to perform all three tasks of the procedural memory test described below.

Declarative memory task

To evaluate declarative memory, we implemented the Wechsler Memory Scale-Revised (WMS-R), Rivermead Behavioral Memory Test (RBMT), and Rey-Osterrieth Complex Figure Test (3-minute delayed recall).

Procedural memory task

In this study, we selected mirror-reading used by Cohen, *et al.*[1] and Martone, *et al.*[11] as a task that incorporates perceptual skill learning, mirror-drawing used by Gabrieli, *et al.*[12] as a task that incorporates motor skill learning, and the Tower of Toronto used by Saint-Cyr, *et al.*[13] as a task that incorporates cognitive skill learning. All three of these tasks were repeated 3 times a day for 3 consecutive days.

1) Mirror-reading task

This task requires reading aloud a 10-line paragraph written in mirror-reversed hiragana as quickly and as accurately as possible. The time required for completion was measured. A unique (non-repeated) paragraph was always prepared for each session. (Fig. 1)

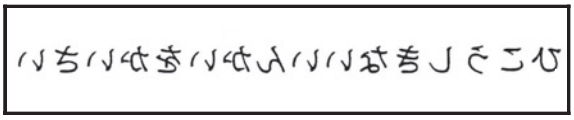

Fig. 1 Mirror-reading test (example)
The subject reads aloud a paragraph written in mirror-reversed hiragana as quickly and as accurately as possible.

2) Mirror-drawing task

Using the device shown in Fig. 2, this task requires tracing of a hexagon with a pencil while looking at the figure reflected in a mirror behind the paper without looking at ones own hands. We measured the time required to make a circuit as quickly and as accurately as possible.

3) Tower of Toronto puzzle

As shown in Fig. 3, this task requires the movement of four discs from the left end bar to the right end bar according to specified rules so that the order of the discs is the same as at the start. There are two rules: only one disc can be moved at a time; and a darker color disc should not be placed on a lighter color disc. We measured the number of times required to solve the puzzle.

Determination

Using a head MRI from the time of hospitalization, based on an evaluation by a neuroradiologist, the presence or absence of lesions in the frontal lobe and the temporal lobe as well as other brain lesions were determined.

In addition, the rate of improvement (%) of the procedural memory task was determined as {(average of the results on the first day − average of the results on the third day)/average of the results on the first day} × 100. This was intended to facilitate a comparison among subjects having different results on the first day, which acts as the baseline. The rate of improvement for each task increases as procedural memory is retained well. We obtained the rate of improvement for each of the three tasks.

For each of the above-mentioned brain lesion localization, the subjects were classified into a group with le-

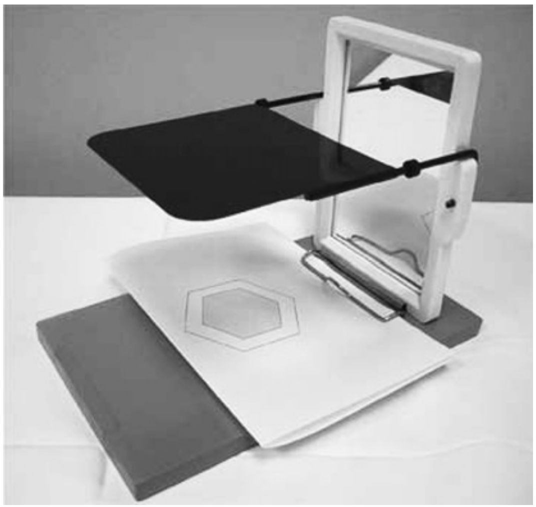

Fig. 2 Mirror-drawing test
The subject traces a hexagon with a pencil while looking at the figure reflected in a mirror behind the paper without looking at his/her hands.

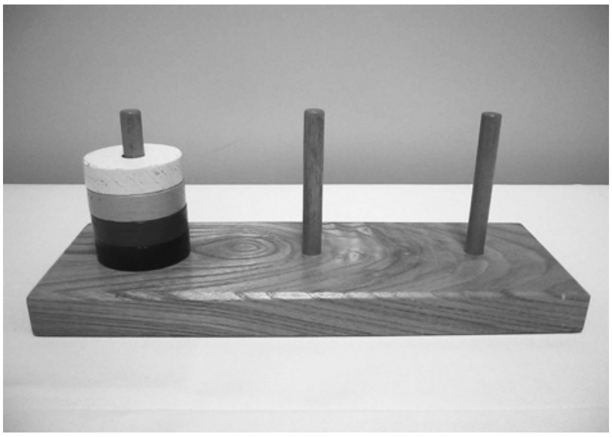

Fig. 3 Tower of Toronto
The subject moves discs from the left end bar to the right end bar according to the guidelines.

Table 1 Profile of the subjects

	TBI patients
Number of subjects (persons)	27
Men/Women (persons)	21/6
Age (years old)	27.6 ± 13.1
Period since the injury (months)	31.6 ± 32.3
WMS-R general memory index	79.1 ± 21.1
WMS-R delayed reproduction index	74.4 ± 21.9
RBMT standard profile score	16.9 ± 4.7
Rey-Osterrieth Complex Figure (reproduction)	34.1 ± 3.0
Rey-Osterrieth Complex Figure (3-minute delayed recall)	19.9 ± 9.5
Presence of lesions in the frontal lobe (persons)	16
Lesions in the cortex + subcortex (persons)	10
Lesions in the prefrontal lobe (persons)	13
Presence of lesions in the temporal lobe (persons)	16
Lesions in the cortex + subcortex (persons)	10
Mirrored reading, the rate of improvement (%)	18.7 ± 17.9
Mirrored drawing, the rate of improvement (%)	47.7 ± 21.5
Tower of Toronto, the rate of improvement (%)	8.3 ± 28.1

Numerical values: average value ± standard deviation after deducting the number of persons
WMS-R: Wechsler Memory Scale-Revised
RBMT: Rivermead Behavioral Memory Test

sions observed and a group without lesions in order to compare the rate of improvement using the Mann-Whitney test (significant level was $p < 0.05$).

III. Results

As shown in Table 1, the subjects comprised 21 men and 6 women with an average age of 27.6 ± 13.1 years. The period from the time of the injury until the examination was 31.6 ± 32.3 months, on average. In addition, the average value of the declarative memory test results was within the range of disorders for all items on the WMS-R general memory index, delayed recall index, standard profile score of the Rivermead Behavioral Memory Test, and Rey-Osterrieth Complex Figure (3-minute delayed recall). In examinations of the damaged sites, 16 subjects had lesions in the frontal lobe, and in 10 of these subjects, overt injuries were observed across the cortical and subcortical areas. A total of 16 subjects had lesions in the temporal lobe, and in 10 of these subjects, overt injuries were observed across the cortical and subcortical areas.

Regarding the correlation between the location of brain damage and the procedural memory test results, Table 2 shows the rate of improvement for each task based on the presence or absence of lesions in the frontal lobe and the temporal lobe. No significant difference was observed in the rate of improvement of the procedural memory, depending on the presence or absence of lesions in the frontal lobe and the temporal lobe.

IV. Discussion

The results of the procedural memory test for all 27 subjects showed the rate of improvement for the mirror-reading to be 18.7 ± 17.9%, mirror-drawing to be 47.7 ± 21.5%, and Tower of Toronto to be 8.3 ± 28.1%. The rate of improvement of one's own experiment cases for 100 healthy individuals (average age of 23.7 ± 1.5 years old) was 24.2 ± 12.3, 53.6 ± 20.2, 26.4 ± 22.1%, respectively. For only the rate of improvement for the Tower of Toronto, the result was significantly favorable for the healthy individuals. The reason for this is believed to be that this task is easily affected by the effect of declarative memory and executive function compared to the other two tasks[14].

Regarding TBI and procedural memory, Ewert, *et al.* conducted tests incorporating the mirror-reading task, the maze task, and the rotary pursuit task for 16 TBI patients. They reported that word recognition in the mirror-reading task was impaired but that all procedural memory test results showed an improvement similar to that of the control group[9]. In addition, Ward, *et al.* conducted tests incorporating the rotary pursuit task and the mirror-reading task for 15 pediatric TBI patients. They reported that recognition of the words used in the mirror reading and objects used in the rotary pursuit were impaired but that the procedural memory was retained[10].

It has also been reported that procedural memory is retained not only in TBI patients but also in patients with amnesia[1)~3)] or Alzheimer's disease[4)~7)]. On the other hand, some cases have been reported in which the procedural memory is impaired. Heindel, *et al.* conducted tests incorporating the rotary pursuit task for patients with Parkinson's disease and Huntington's disease. They reported that procedural memory was impaired in both groups[7]. In addition, Martone, *et al.* used the mirror-reading task for patients with Huntington's disease[11], and Saint-Cyr, *et al.* used the Tower of Toronto for patients with Parkinson's disease[13]. They each reported an impaired procedural memory. From these reports, it is assumed that the commonly affected basal ganglia area is mainly responsible for the acquisition of procedural memory. It has been pointed out that the cerebellum is also associated with procedural memory in addition to the basal ganglia. Yamadori, *et al.* conducted a test incorporating the mirror-reading task involving 9 patients with early phase spinocerebellar degeneration in addition to 10 untreated patients with early phase Parkinson's disease. They reported that word recognition and acoustic language learning were similar to those of healthy individuals but that procedural memory was impaired in both groups[15]. Pascual-Leone, *et al.* used a series reaction time task for patients with spinocerebellar degeneration and Parkinson's disease and reported impaired procedural memory[16].

Furthermore, Pascual-Leone, *et al.*[16] noted the difference in responsibilities of the basal ganglia and the cerebellum. A learning effect was not observed in patients with spinocerebellar degeneration, but it was to some extent in patients with Parkinson's disease. When the task became complicated, no difference was found in the reaction time, and the learning effect declined. From these results, they concluded that the basal ganglia and the prefrontal area appear to exchange information as needed and that in patients with Parkinson's disease, procedural memory was impaired, in a test that required the multiple repetition of complicated tasks. On the other hand, they stated that the cerebellum appears to serve to store memories of events at an appropriate time in an appropriate order and that the capability to do so becomes insufficient in patients with spinocerebellar degeneration, resulting in impaired procedural memory. Regarding the difference in association between the basal ganglia, the cerebellum, and the procedural memory, Penhune, *et al.* state that the cerebellum is involved in the initial phase of motor learning and that the basal ganglia are involved in a later phase, thereby becoming automatic[17]. As such, even though the basal ganglia and the cerebellum are significantly involved in procedural memory, the roles thereof have not yet been clearly determined.

Table 2 Rate of improvement for the three tasks

		Mirror-reading	P-value	Mirror - drawing	P-value	Tower of Toronto	P-value
Frontal lobe lesion	+ (16)	15.9 ± 19.8	0.72	46.0 ± 21.5	0.75	9.0 ± 30.4	0.82
	− (11)	22.7 ± 14.6		50.1 ± 22.3		7.4 ± 25.6	
Temporal lobe lesion	+ (16)	21.8 ± 17.3	0.15	47.1 ± 22.2	0.87	10.6 ± 23.6	0.65
	− (11)	14.0 ± 18.6		48.5 ± 21.4		5.0 ± 34.5	

Numerical values: average value ± standard deviation
The numeral in parentheses indicates the number of persons
P-value: Mann-Whitney test

In general, the common sites of cortical contusion in TBI include the anterotemporal and orbitofrontal regions, and others. For diffuse axonal injuries, common sites include the corpus callosum, and parasagittal white matter as well as the dorsolateral quadrants of the midbrain, and others[18]. These sites differ from those (basal ganglia, cerebellum) regarded as being strongly involved in the above-mentioned procedural memory. From the results of this study, as shown in Table 2, regarding lesions in the frontal lobe and the temporal lobe, it cannot be said that the rate of improvement significantly decreases for all three tasks of the procedural memory test due to lesions at these sites. This conforms with past views in terms of the main focus of procedural memory. It is believed that the correlation between the location of damage due to TBI, particularly brain contusions, and the procedural memory is low.

Beldarrain, *et al.* conducted a visuomotor series reaction time task for 22 patients with unilateral prefrontal lobe damage, including 9 TBI patients. They reported that disorders were found in the reaction of both upper limbs[19], which suggests that the prefrontal lobe also plays a specific role in procedural memory. In this study, 13 patients had lesions in the prefrontal lobe among the 16 patients who had lesions in the frontal lobe. However, it cannot be said that the results declined in all three tasks of the procedural memory test due to lesions in the frontal lobe. As for reasons for the incompatible results, it is believed that different test tasks were used, damage in the frontal lobe can easily lead to executive dysfunction, the effect of executive dysfunction should therefore be taken into consideration when reviewing procedural memory test results, 9 of 22 subjects in the study by Beldarrain, *et al.* had TBI, and the mechanism of brain damage differed from that in our subjects. Further examination of the correlation between the frontal lobe and the procedural memory will thus be necessary in the future.

It was difficult to examine the cerebellum and the basal ganglia that appear to be involved in procedural memory, because only 3 patients had lesions in the cerebellum and one patient had a lesion in the basal ganglia in this study. In some cases, the blood flow at both sites decreased in subjects who underwent cerebral blood flow scintigraphy. In one case, SPECT showed a low blood flow in both cerebellum hemispheres wherein the presence of lesions could not be detected from an MRI , and the rate of improvement was low for all three tasks. However, in other cases, the rate of improvement was favorable for the three tasks, despite the declined blood flow to both cerebellum hemispheres. Therefore, we could not determine any specific tendency.

V. Conclusion

We examined the correlation between the location of brain damage in chronic phase TBI patients and procedural memory test results. From the results of this study, it is believed that there was little correlation between the procedural memory and damage in the frontal lobe and the temporal lobe, which are common sites of cerebral contusions. In the future, it will be necessary to increase the number of cases, including bilateral impairment, as well as to evaluate the cerebral blood flow and perform an analysis regarding the overlapping of damaged sites in addition to investigating the effect of diffuse axonal injuries. It is expected that further such studies would enable us to obtain new findings that would be valuable in the cognitive rehabilitation and vocational rehabilitation using procedural memory.

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外傷性脳損傷患者の前頭葉・側頭葉病変と手続き記憶

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―キーワード―
外傷性脳損傷，手続き記憶，脳挫傷

【目的】外傷性脳損傷（以下 TBI）の認知リハビリテーションにおいて残存する手続き記憶を活用することは重要である．これまで TBI 患者の脳損傷部位と手続き記憶について検討した報告は乏しく，今回我々は TBI 患者の慢性期の頭部 MRI で同定した損傷部位と手続き記憶の検査成績の関連について検討した．

【対象と方法】高次脳機能障害の評価を主目的に当科入院し，手続き記憶検査の 3 課題（鏡映読字，鏡映描画，トロントの塔）の全てが施行可能であった TBI 患者 27 名を対象とした．頭部 MRI を用いて損傷部位を同定し前頭葉・側頭葉病変の有無を判定した．陳述記憶の評価としてウェクスラー記憶検査，リバーミード行動記憶検査，Rey 複雑図形 3 分後再生を行った．手続き記憶の 3 課題は各々 1 日に 3 回ずつ繰り返し，連続した 3 日間施行した．手続き記憶課題の改善率（%）は {(1 日目の成績の平均値－3 日目の成績の平均値)/1 日目の成績の平均値} ×100 と定義し，3 課題各々の改善率を求めた．患者を前頭葉と側頭葉の病変の有無で分け，それぞれの改善率を Mann-Whitney 検定を用いて比較した（有意水準 $p<0.05$）．

【結果】陳述記憶の検査成績の平均値はいずれの検査においても障害域であった．前頭葉病変，側頭葉病変のいずれも損傷の有無によって手続き記憶の改善率に有意な差異を認めなかった．

【結論】手続き記憶は大脳基底核や小脳の関与が大きいと考えられており，TBI 患者では陳述記憶は障害されるが手続き記憶は保持されやすいと言われている．今回の結果からも TBI の好発部位である前頭葉・側頭葉損傷と手続き記憶との関連は低いと考えられた．

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