Predictive value of Wada memory scores on postoperative learning and memory abilities in patients with intractable epilepsy

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Object. Surgery for refractory epilepsy often bestows significant relief but may cause memory impairment. The risk of postsurgical memory loss can be determined by the intracarotid amobarbital procedure, or the Wada test. Chemical inactivation of the hemisphere on the side of the lesion is usually performed first, followed by inactivation of the contralateral hemisphere. Patients who demonstrate adequate memory capacity of the contralateral hemisphere following deactivation of the ipsilateral hemisphere are considered good candidates for anterior temporal lobectomy. Evidence for the contribution of deactivating the contralateral healthy hemisphere remains inconclusive.

Methods. The authors analyzed results in 32 patients with intractable epilepsy who had undergone a bilateral Wada test followed by an anterior temporal lobectomy and in whom the findings of both pre- and postsurgical neuropsychological evaluations were available. The Wada memory scores were correlated with the difference in scores between pre- and postsurgical standardized memory test scores.

Conclusions. Analyses revealed no significant relationship between the Wada memory scores in the contralateral hemisphere and postsurgical changes in memory abilities. There was, however, a significant negative correlation between the Wada memory score in the ipsilateral hemisphere and postsurgical memory changes, particularly in patients with right hemisphere epileptogenic lesions (p = 0.0007). The results of this study are discussed vis-à-vis two theories of hippocampal function, and the authors stress the importance of the functional status of the surgical hemisphere in the prediction of postsurgical memory changes.

Key Words • Wada test • learning • memory • epilepsy surgery

Anterior temporal lobectomy is considered an effective treatment in patients with medically refractory epilepsy, although it is associated with a risk of memory decline. The IAP, or the Wada test, is used to assess the postsurgical risk of global amnesia. The ability of the contralateral, healthy hemisphere to sustain memory functions can be evaluated by temporary pharmacological inactivation of each hemisphere. Reports of postsurgical global amnesia have become rare since the application of the Wada test for assessing the suitability of epileptic patients for surgery. Note, however, that milder deficits in material-specific memory following this surgical procedure have been reported in patients who performed well on the Wada test, and attempts have been made to predict the mild memory deficits based on a patient’s performance on the Wada test.

A decline in verbal memory after left temporal lobectomy is well documented, but the status of nonverbal memory after right temporal lobectomy is less clear. Postsurgical memory changes have been associated with presurgical neuropsychological test results, age at seizure onset, hippocampal pathological characteristics, and postsurgical seizure control. Authors examining the relationship between Wada memory measures and postoperative memory status have used both the Wada asymmetry score and the Wada individual scores (that is, the ipsilateral and contralateral memory scores) as predictors of postsurgical memory changes.

Two models of hippocampal functioning have emerged from these studies and were proposed for application in forecasting memory changes after temporal lobe surgery. According to the functional reserve model, the functional integrity of the mesial temporal lobe structures contralateral to the hemisphere with the seizure focus determines the postsurgical memory outcome. Injection of sodium amytal into the hemisphere ipsilateral to the presumed seizure focus temporarily inactivates the surgical hemisphere and isolates cognitive functions in the contralateral hemisphere. Memory testing during this reversible state allows modeling of the possible effects of surgery on memory outcome. Patients who demonstrate good functional status of the contralateral hemisphere are expected to...
have a good memory outcome after surgery, whereas those patients who experience difficulties in encoding and storage of the presented stimuli are expected to have some memory loss after surgery.

Chiaravalloti and Glosser have presented evidence in support of the functional reserve model. They studied the relationship between material-specific aspects of the Wada memory assessment and changes in memory after ATL in 70 patients with medically refractory seizures. They found that patients who had undergone left ATL experienced a decline in verbal memory, whereas patients who had undergone right ATL had a decline in visuospatial memory. These authors also demonstrated that Wada total recognition memory scores and verbal memory scores were associated with postoperative verbal memory decline. This relationship was shown to be significant for the ipsilateral IAP as well as asymmetry scores, but not for the contralateral IAP. The authors concluded that a postoperative verbal memory change is significantly related to Wada verbal memory after an ipsilateral IAP, reflecting the importance of the functional status of the contralateral hemisphere and supporting the functional reserve model of memory change in ATL.

In contrast, other researchers have maintained that although the functional integrity of the contralateral temporal lobe is important in predicting postsurgical global amnesia, it is not a good predictor of milder memory deficits. Thus, according to the functional adequacy model, it is the functional status of the hemisphere subject to resection that determines the nature and extent of the postsurgical graded memory deficits. Chelune stated that significant decrements in memory following temporal lobe surgery seem to occur mostly in patients whose memory abilities, according to the results of Wada testing, had been intact before surgery. Similarly, Sabsevitz, et al., claimed that there is an increased risk of verbal memory decline (and significantly worse seizure outcome) in patients with reversed Wada memory asymmetry, that is, in patients whose Wada memory score was higher on the surgical as opposed to the nonsurgical hemisphere.

Clinical evidence for establishing which injection is more predictive of milder forms of memory changes following surgery for the relief of TLE remains contradictory. According to the functional reserve model, memory performance after injection into the hemisphere ipsilateral to the seizure focus predicts postsurgical memory decline. According to the functional adequacy model, memory performance after injection into the hemisphere contralateral to the seizure focus predicts postsurgical memory decline.

The purpose of this retrospective study was to test the hypothesis of the functional reserve model compared with the functional adequacy model on postsurgical memory changes in epileptic patients in light of the relative benefits and risks of the IAP. The clinical significance of this study is the
prediction of the extent of postsurgical memory deficits in elective neurosurgery.

Clinical Material and Methods

Patient Population

All patients in this study suffered from TLE and were candidates for unilateral resection of the epileptic focus for control of intractable seizures at the Tel Aviv Sourasky Medical Center. There were 19 patients (nine male and 10 female) with left hemisphere epilepsy and 13 patients (nine male and four female) with right hemisphere epilepsy. There were no significant differences between the two groups in terms of age, years of education, or intelligence quotient. The following selection criteria were applied to the two patient groups: presence of a unilateral epileptogenic zone, no history of a primary psychiatric diagnosis, no mental retardation, and technically valid Wada test results. All patients had undergone ATL which involved resection of mesial temporal lobe structures for removal of the epileptogenic focus. The laterality of the epileptogenic focus was determined through concordance of results of videoelectroencephalographic monitoring, structural and fMR imaging, single-photon emission computerized tomography scanning, positron emission tomography scanning, magnetoencephalography studies, and neuropsychological examination. All patients had undergone bilateral Wada testing to determine cerebral language dominance and unilateral memory potential as well as extensive presurgical neuropsychological examination including measures of general intelligence, memory, language, perceptual abilities, motor and executive functions and emotional status. A summary of patient characteristics is presented in Table 1.

Neuropsychological Assessment

Memory Assessment. The comprehensive presurgical neuropsychological assessment included testing for evaluation of memory function. The results of the RAVLT and the RCFT were chosen for analysis because these tests have been standardized for the Hebrew language. Scores for total learning of 15 words (RAVLT-T, representing the sum of the first five trials), RAVLT-5 (5th trial score) and RAVLT-8 (the score on the 8th trial), as well as the long-term recall of the RCFT have been used as learning and memory indices. Estimated surgery-related changes in memory were reflected in the difference scores computed on the same memory tests administered to patients before and 1 year after surgery, as part of the follow-up examination. The memory discrepancy score, D, (postsurgical score minus presurgical score) was calculated for all memory measures; a positive score reflected an improvement in memory function and a negative score reflected a decline.

Intracarotid Amobarbital Procedure. The patients underwent an IAP according to the protocol developed at the Tel Aviv Sourasky Medical Center. After a vascular anatomy examination, a catheter was placed in the internal carotid artery via a transfemoral approach. None of the patients exhibited evidence of significant cross-flow or anomalous vascularization that would affect the interpretation of test results. Intracarotid artery injections of sodium amobarbital were administered by hand for 4 to 5 seconds through the catheter. The mean dosage was 106.40 mg for injections into the left hemisphere and 107.46 mg for injections into the right hemisphere. The hemisphere ipsilateral to the epileptogenic focus was injected first. Language testing followed by the presentation of eight objects for recall began with the establishment of contralateral hemiplegia. Language evaluation involved following simple commands, naming eight objects, reading, and repeating words and sentences. Disruption in any of the language tasks and the appearance of paraphasias on recovery were taken as signs of language representation in the injected hemisphere. Memory testing started approximately 10 minutes after injection, following complete recovery of motor and language functions. Recognition was assessed through the identification of the target stimulus among an array of two foil items. The recognition of at least 67% of the items was categorized as a passing score. After a 30-minute interval, an identical procedure was applied to the other hemisphere. Three Wada memory scores were computed for each patient: the percentage of memory items recognized on ipsilateral injection (ipsilateral memory score), and the asymmetry score (reflecting the relative capacity of the two hemispheres). The absolute value of the asymmetry scores was calculated by subtracting the smaller from the larger memory score.

Statistical Analysis

A series of one-way analyses of variance were performed to examine group differences on the neuropsychological and Wada memory measures. The Pearson correlation coefficient was applied to analyze the relationships between the three Wada memory measures and the discrepancy scores.

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**TABLE 2**

<table>
<thead>
<tr>
<th>Wada Test &amp; Hemisphere</th>
<th>Patients w/ LH TLE</th>
<th>Patients w/ RH TLE</th>
<th>All Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>ipsilateral memory</td>
<td>30.74 ± 30.62</td>
<td>32.87 ± 33.04</td>
<td>27.63 ± 27.69</td>
</tr>
<tr>
<td>contralateral memory</td>
<td>81.17 ± 11.44</td>
<td>80.35 ± 11.14</td>
<td>82.37 ± 12.23</td>
</tr>
<tr>
<td>asymmetry score</td>
<td>50.43 ± 30.08</td>
<td>47.48 ± 32.62</td>
<td>54.74 ± 26.59</td>
</tr>
</tbody>
</table>

* LH = left hemisphere; RH = right hemisphere.

**TABLE 3**

<table>
<thead>
<tr>
<th>Test</th>
<th>Discrepancy Score (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All Patients</td>
</tr>
<tr>
<td>RAVLT-T</td>
<td>2.45 ± 9.19</td>
</tr>
<tr>
<td>RAVLT-5</td>
<td>−0.26 ± 2.72</td>
</tr>
<tr>
<td>RAVLT-8</td>
<td>−0.16 ± 3.53</td>
</tr>
<tr>
<td>RCFT/LTR</td>
<td>2.64 ± 5.28</td>
</tr>
</tbody>
</table>

* The discrepancy scores represent the postsurgical minus the presurgical scores. A positive score indicates improvement in memory function, whereas a negative score reflects a decline. Abbreviation: LTR = long-term recall.
on the standard memory tests. The contribution of each Wada score in predicting postsurgical memory changes was examined using a set of multiple regression analyses.

**Results**

The group means and SDs for the three Wada memory scores are presented in Table 2, and the group means and SDs for the four memory discrepancy scores are presented in Table 3. The results of a two-tailed Pearson correlational analysis of the relationship between the neuropsychological and Wada memory scores in all patients are presented in Table 4. No significant relationship was found between the Wada scores for contralateral memory (that is, memory abilities of the healthy hemisphere) and postsurgical changes on standard neuropsychological memory tests. On the other hand, there was a significant negative correlation (r = −0.42, p = 0.02) between the Wada scores for ipsilateral memory (that is, memory abilities of the surgical hemisphere) and postsurgical changes in verbal learning, as measured using the RAVLT-5.

There was a significant positive correlation between the Wada asymmetry score and all measures of verbal learning, suggesting that a high Wada asymmetry score is associated with an improvement in postsurgical verbal learning ability. This trend was observed for all measures of verbal learning and memory: r = 0.35 and p = 0.05 for RAVLT-T, r = 0.34 and p = 0.05 for RAVLT-5, and r = 0.36 and p = 0.04 for RAVLT-8 (Table 4).

The results of separate statistical analyses for patients with left-hemisphere as opposed to right-hemisphere epileptogenic lesions are presented in Tables 5 and 6, respectively. Negative correlations between Wada scores for ipsilateral memory and all standard memory tests were observed in the group with left hemisphere epilepsy, but none of them reached a level of statistical significance. In contrast, patients in the group with right hemisphere epilepsy showed a highly significant negative relationship between Wada scores for ipsilateral memory and postsurgical learning ability especially in the parameter of best learning (RAVLT-5: r = −0.81 and p = 0.0007). An increase in postsurgical learning ability was also significantly positively correlated with Wada asymmetry scores in these patients (r = 0.63 and p = 0.02). This trend, which was particularly strong in patients with right-hemisphere epileptogenic lesions, can be clearly observed in Fig. 1 (p of interaction = 0.01).

Most patients with right hemisphere epilepsy showed an increase in verbal learning and memory, whereas most patients with left hemisphere epilepsy showed a decrease in these abilities. A decline in the retention of newly learned verbal material (RAVLT-8) compared with the presurgical level was observed in patients who had undergone surgery in the dominant hemisphere (mean D = −1.56, 18 patients [16 with left hemisphere and two with right hemisphere epilepsy]). On the other hand, patients who had undergone surgery on the nondominant hemisphere showed an improvement in the retention of newly learned material (mean D = 1.77, 14 patients [12 with right hemisphere and two with left hemisphere epilepsy]). This difference reached a level of statistical significance (p = 0.007), stressing the importance of language laterality in postsurgical memory changes.

Using a two-tailed t-test, we examined the question of whether postsurgical improvement in learning ability dem-

**TABLE 4**

<table>
<thead>
<tr>
<th>Discrepancy Score</th>
<th>Wada Contralat Score</th>
<th>p Value</th>
<th>Wada Ipsilat Score</th>
<th>p Value</th>
<th>Wada Asymmetry Score</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAVLT-T</td>
<td>0.08</td>
<td>0.64</td>
<td>−0.31</td>
<td>0.09</td>
<td>0.35</td>
<td>0.05*</td>
</tr>
<tr>
<td>RAVLT-5</td>
<td>−0.22</td>
<td>0.24</td>
<td>−0.42</td>
<td>0.02*</td>
<td>0.34</td>
<td>0.05*</td>
</tr>
<tr>
<td>RAVLT-8</td>
<td>0.25</td>
<td>0.18</td>
<td>−0.27</td>
<td>0.15</td>
<td>0.36</td>
<td>0.04*</td>
</tr>
<tr>
<td>RCFT-LTR</td>
<td>0.22</td>
<td>0.27</td>
<td>−0.04</td>
<td>0.82</td>
<td>0.15</td>
<td>0.46</td>
</tr>
</tbody>
</table>

* Indicates statistical significance.

**TABLE 5**

<table>
<thead>
<tr>
<th>Discrepancy Score</th>
<th>Wada Contralat Score</th>
<th>p Value</th>
<th>Wada Ipsilat Score</th>
<th>p Value</th>
<th>Wada Asymmetry Score</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAVLT-T</td>
<td>0.07</td>
<td>0.79</td>
<td>−0.23</td>
<td>0.36</td>
<td>0.25</td>
<td>0.31</td>
</tr>
<tr>
<td>RAVLT-5</td>
<td>0.01</td>
<td>0.94</td>
<td>−0.15</td>
<td>0.55</td>
<td>0.16</td>
<td>0.53</td>
</tr>
<tr>
<td>RAVLT-8</td>
<td>0.36</td>
<td>0.14</td>
<td>−0.31</td>
<td>0.21</td>
<td>0.43</td>
<td>0.08</td>
</tr>
<tr>
<td>RCFT-LTR</td>
<td>0.30</td>
<td>0.32</td>
<td>−0.13</td>
<td>0.66</td>
<td>0.26</td>
<td>0.39</td>
</tr>
</tbody>
</table>
Constrasted by the patients with right hemisphere epileptogenic lesions could be related to cerebral language laterality. The mean Wada asymmetry score was 40.1 when language was in the ipsilateral hemisphere (18 patients [left hemisphere and two right hemisphere lesions]). Note, however, that when language was in the hemisphere contralateral to the site of surgery (14 patients [with right hemisphere and two with left hemisphere epilepsy]), the Wada asymmetry score was 63.7. This difference reached a level of statistical significance (*p = 0.025*).

**Discussion**

The main result of this study is the demonstrated importance of the functional adequacy of the ipsilateral hippocampus to be resected in predicting mild memory changes after surgery for epilepsy. Although there was no significant relationship between the Wada memory scores for the contralateral hemisphere and postsurgical memory changes, there was a significant negative correlation between the Wada memory scores for the ipsilateral hemisphere and postsurgical changes in verbal learning and memory abilities. In addition, the significant positive correlation that emerged between the Wada asymmetry scores and all measures of verbal learning and memory changes supports this finding, given that high asymmetry scores resulted from low ipsilateral memory function and not high contralateral memory function during the Wada test. The results of our study demonstrate the importance of the functional status of the surgical hemisphere and thus the value of a second Wada injection in predicting postsurgical memory changes in candidates for epilepsy surgery.

A separate analysis of the data in both the patients with left hemisphere and those with right hemisphere epilepsy yielded additional information on this issue and indicated that an improvement in postsurgical memory function may occur under certain conditions. Although patients with high memory potential in the presurgical left hemisphere had an increased chance of suffering postoperative memory decline (despite having performed well on the Wada test), patients with low ipsilateral memory potential in the presurgical right hemisphere demonstrated postoperative improvement in memory function. In particular, the results of this study suggested that patients with right hemisphere epileptogenic lesions who demonstrate low memory capacity in the hippocampus to be resected may improve their learning ability after surgery.

Our data supported the view that the risk of memory decrements following mesial temporal lobe surgery is inversely related to the functional adequacy of the tissue to be resected. These findings stress the importance of the ipsilateral memory on predictions of mild to moderate postoperative memory changes. Patients with low preoperative memory potential of the sclerotic hippocampus (particularly in patients with right hemisphere epileptogenic lesions) may experience improvement in verbal learning and memory after surgery. On the other hand, patients with high memory potential, particularly in the language-dominant hemisphere, are at risk of postsurgical memory decline. A post hoc analysis of the relationship between cerebral language dominance and postoperative seizure outcome revealed interesting results: 11 (78.5%) of 14 patients who had undergone surgery in the nondominant hemisphere were seizure free compared with only nine seizure-free patients (50%) among the 18 who had undergone surgery in the dominant hemisphere. Thus, more patients tended to be seizure free when cerebral language dominance was not on the side subjected to surgery (*χ² = 0.09*). Nonetheless, given that most patients with left hemisphere epileptogenic lesions underwent surgery in the language-dominant hemisphere and that

**TABLE 6**

<table>
<thead>
<tr>
<th>Discrepancy Score</th>
<th>Wada Contralat Score</th>
<th>p Value</th>
<th>Wada Ipsilat Score</th>
<th>p Value</th>
<th>Wada Asymmetry Score</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAVLT-T</td>
<td>0.05</td>
<td>0.87</td>
<td>−0.47</td>
<td>0.09</td>
<td>0.51</td>
<td>0.07</td>
</tr>
<tr>
<td>RAVLT-5</td>
<td>0.47</td>
<td>0.10</td>
<td>−0.81</td>
<td>0.0007*</td>
<td>0.63</td>
<td>0.02†</td>
</tr>
<tr>
<td>RAVLT-8</td>
<td>−0.02</td>
<td>0.96</td>
<td>−0.10</td>
<td>0.74</td>
<td>0.10</td>
<td>0.74</td>
</tr>
<tr>
<td>RCFT-LTR</td>
<td>0.12</td>
<td>0.70</td>
<td>0.14</td>
<td>0.66</td>
<td>−0.09</td>
<td>0.78</td>
</tr>
</tbody>
</table>

* Indicates a highly significant negative relationship. † Indicates a significantly positive relationship.

**FIG. 1.** Graph depicting the interaction between Wada memory scores for the ipsilateral memory scores and postsurgical changes in memory in patients with left (LH) versus right (RH) hemisphere epileptogenic lesions. RAVLT_SD = difference score on the best learning trial of the RAVLT; Wada_IPSI = memory score of the hemisphere ipsilateral to the epileptogenic focus on the Wada test.
most patients with right hemisphere epileptogenic lesions underwent surgery in the non–language-dominant hemisphere, cerebral language laterality and laterality of surgical intervention remain confounding factors in this sample of patients. The results of the present study are in accord with those reported in the literature in support of the functional adequacy model. As the data presented by Sabsevitz, et al. suggests, any degree of reversed asymmetry reflecting an intact or minimally sclerotic hippocampus and preserved ipsilateral memory places the patient at risk for verbal memory decline after surgery. The authors did not mention whether the same holds true in patients with right hemisphere epileptogenic seizures. Our results are also in accord with those of Lee and colleagues who found high correlations between Wada asymmetry scores and seizure-free outcomes. In the present study, higher asymmetry scores were observed in patients with right hemisphere epileptogenic foci, whose surgical hemisphere was not the language-dominant one, who demonstrated low ipsilateral memory on the Wada test, and who tended to be seizure free after surgery. White, et al. examined the relationship between Wada memory scores after the contralateral injection and that after postsurgical memory loss. They found that patients with left hemisphere epileptogenic foci and good memory scores on the second contralateral injection suffered greater decrements in memory compared with patients who showed poor memory capacity in the surgical hemisphere. The authors concluded that the functional adequacy of the surgical temporal lobe rather than the functional reserve of the contralateral hemisphere is most related to typical memory changes following epilepsy surgery. Removal of the epileptogenic but functionally adequate mesial lobe structures may lead to postsurgical memory decline, whereas removal of poorly functioning mesial temporal structures, as defined on Wada testing, should not lead to further memory decline.

In contradiction with our results, Chiaravalloti and Glosser observed no significant relationship between Wada memory scores for the ipsilateral hemisphere and the postoperative differences in verbal memory. One of the reasons for this divergence of results may be the difference in how memory was assessed in the two studies: Chiaravalloti and Glosser used memory recognition measures, whereas we used learning measures in our study. This point raises the question of the sensitivity of different memory measures for assessing hippocampal function. Our choice was based on data presented by Jones-Gotman and colleagues who suggested that learning ability measures are the most sensitive for hippocampal function and dysfunction. The results of our study support their position on the sensitivity of verbal learning measures for determining memory changes.

The lack of a significant relationship between Wada contralateral memory scores and postoperative memory changes in our study may be related to the low variability of these scores given that only those patients who demonstrated high memory function in the healthy hemisphere subsequently underwent surgery. Indeed, none of these patients experienced postoperative global memory loss. The memory deficits observed in this sample of patients, particularly those with left hemisphere epileptogenic lesions, seem to be related to high ipsilateral memory capabilities, as reflected in the high Wada scores. Another source for postoperative memory decline in patients with left hemisphere lesions may have been encroachment of the resection on lateral cortical sites that were perhaps important for input or storage of recent verbal memory, as noted by Ojemann.

Thus, our results suggest that the information provided by the Wada test, namely, advanced knowledge of the cerebral language dominance and memory potential of the hemisphere designated for surgery, is highly important for preoperative patient counseling before elective epilepsy surgery. Nonetheless, there are still concerns and controversies regarding the Wada test. For instance, opinions vary not only on the justification of the neuropsychological information yielded by the second amobarbital injection in light of the medical risk factors associated with angiography, but also on the general utility and validity of this test. Helmstaedter and Kurthen suggest that although it is desirable to predict graded memory outcome for individual patients, it does not justify the medical risk of the Wada procedure. It has been proposed that the goals of the Wada test could be partially achieved by noninvasive methods, such as baseline neuropsychological testing and memory fMR imaging. Patients with intact memory ability in the language-dominant hemisphere, as demonstrated on presurgical neuropsychological assessment, fMR imaging, and magnetoencephalography, perhaps should be cautioned about possible postsurgical memory decline.

Conclusions

The results of the present study suggest that the functional integrity of both the contralateral hemisphere (1st injection) and the ipsilateral hemisphere (2nd injection) is important for the prediction of postoperative memory changes. Demonstration of good memory abilities in the hemisphere contralateral to the epileptogenic focus will prevent postoperative global amnesia, whereas demonstration of good memory abilities in the ipsilateral hemisphere—especially the language-dominant one—may represent a risk factor for postoperative mild to moderate memory decline. In addition, our results indicate that patients with poor memory capacity in the right language-nondominant epileptogenic hemisphere tend to improve in memory function after surgery and tend to have a better chance of remaining seizure free after surgery. Patients with high memory potential in the left language-dominant hemisphere who are candidates for surgical removal of the epileptogenic focus should be warned of possible postoperative memory decline, even though they have scored well on the preoperative Wada test. Future studies should include larger patient samples and investigation of the correlations between Wada ipsilateral memory, neuropsychological test performance, and fMR imaging memory measures.

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References

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