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Selective Amygdalohippocampectomy for Hippocampal Sclerosis: Postoperative MR Appearance

S. A. Renowden, Z. Matkovic, C. B. T. Adams, K. Carpenter, S. Oxbury, A. J. Molyneux, P. Anslow, and J. Oxbury

PURPOSE: To analyze the anatomic consequences of selective amygdalohippocampectomy (AH) in patients with hippocampal sclerosis and to correlate the clinical outcome with the MR appearance. **METHODS:** Seventeen patients were examined with clinical and neuropsychologic examination and cranial MR after AH (7 transcortical AH, 10 trans-Sylvian AH). The clinical and neuropsychologic outcomes after AH were compared with those of anterior lobectomy (ATL). **RESULTS:** There was no significant difference in seizure cure between transcortical or trans-Sylvian AH and ATL. However, patients with left AH fared significantly better in terms of verbal IQ and nonverbal memory when compared with those with left ATL. Verbal memory and cognition were not significantly different in the two AH groups. Variable amounts of hippocampal and amygdala remnants were found in both AH groups and did not correlate with seizure cure. White matter change consistent with gliosis probably secondary to wallerian degeneration was demonstrated in the anterior temporal lobe to a mean distance of 4.5 cm after transcortical AH and to a lesser degree as a consequence of trans-Sylvian AH. Nine patients (53%) (4 transcortical AH, 5 trans-Sylvian AH) demonstrated wallerian degeneration in the optic radiations after surgery. All had incomplete contralateral quadrantanopia. **CONCLUSIONS:** There is more secondary damage to the temporal lobe after AH than was previously recognized. The extent of hippocampal and amygdala resection in AH do not seem to be directly related to seizure cure. Visual field defects are common in AH because of the anterior but variable course of the optic radiations.

Index terms: Sclerosis, hippocampal; Surgery, resective; Magnetic resonance, postoperative

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Selective amygdalohippocampectomy (AH) has been recommended as a surgical treatment for intractable epilepsy of unilateral mesobasal temporal lobe origin. The main objective of AH is to spare the lateral neocortex on the grounds that the seizure relief is comparable to that produced by a standard en bloc temporal lobectomy, and the neuropsychologic outcome is better (1). Several methods for the selective resection of the mesial temporal structures have been advocated, including the transcortical route of Niemeyer (2) and the trans-Sylvian route of Yasargil et al (3).

Preliminary studies at our institution were unable to demonstrate a clear advantage in terms of seizure cure or memory and cognition of these methods of AH over en bloc anterior temporal lobectomy (ATL) during the first postoperative year (4). As part of a continuing evaluation of different surgical approaches to the surgical treatment of intractable temporal lobe epilepsy, we have conducted a magnetic resonance (MR) analysis of the anatomic consequences of transcortical and trans-Sylvian AH. The data are related to the outcome of the surgical treatment.

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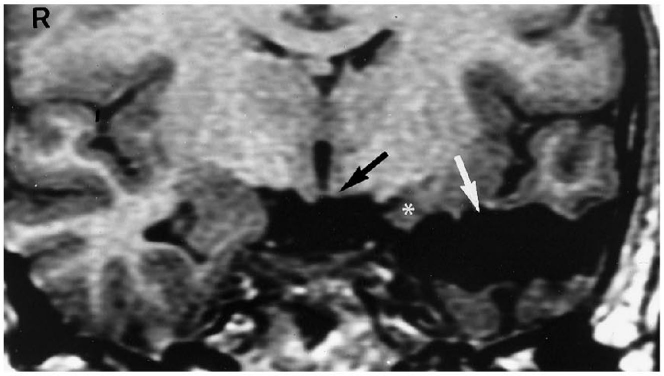

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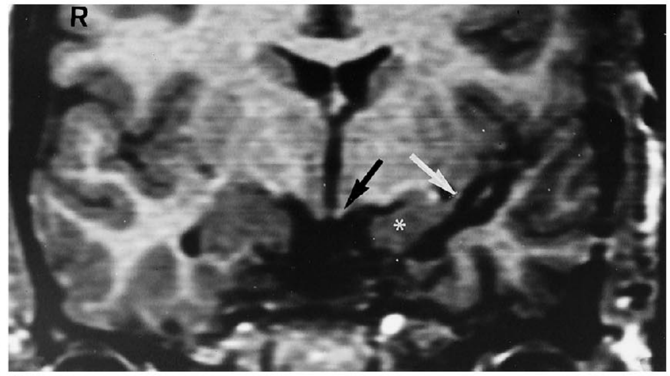

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Fig 1. Coronal spoiled gradient-echo MR image (35/5/1 [repetition time/echo time/excitations], 35° flip angle, 256 × 128 matrix) demonstrates the resection path (*white arrow*) through the left middle temporal gyrus and across the anterior temporal lobe, to gain access to the mesial temporal structures in a transcortical AH. The amygdala has been largely resected on the left. The small remnant is indicated (*asterisk*). Incidental note is made of an atrophied left mamillary body as a result of AH (*black arrow*).

Fig 2. Coronal spoiled gradient-echo MR image (35/5/1, 35° flip angle, 256 × 128 matrix) demonstrates the resection path (*white arrow*) through the left Sylvian fissure and across the anterior temporal lobe, to gain access to the mesial temporal structures in a trans-Sylvian AH. The amygdala (*asterisk*) has been incompletely removed on the left. The left mamillary body is atrophic (*black arrow*).

Patients and Methods

Seventeen patients in whom preoperative investigation revealed no disease other than hippocampal sclerosis underwent AH. These 17 were from a consecutive series of 22 patients who underwent a selective AH procedure for drug-resistant epilepsy caused by hippocampal sclerosis during 1989 through 1992. Five of the 22 could not be assessed with MR after surgery: 2 were pregnant; 1 had been operated on again (anterior temporal lobectomy); 1 had a retained fragment of a sphenoidal electrode; and 1 was unavailable. One of us (C.B.T.A.) was the surgeon in 15 cases, and Richard Kerr operated on the other 2.

Seven patients were operated on via the transcortical approach of Niemeyer (2) through the middle temporal gyrus (Fig 1): five women and two men; age range, 18 to 37 years; mean age, 24 years; five left sided and two right sided. Ten were operated on via the trans-Sylvian approach of Yasargil et al (3) (Fig 2): six women and four men; age range, 16 to 32 years; mean age, 23.3 years; eight left sided and two right sided.

In all cases hippocampal sclerosis was verified histologically. Preoperative assessment included activated sphenoidal encephalography, prolonged video telemetry, cranial MR with volumetric studies, positron-emission tomography, detailed neuropsychologic analysis, and carotid amytal language and memory testing. After surgery the patients were assessed clinically at 3, 6, 12, and 24 months, neuropsychologically at 6 and 24 months, and with cranial MR with volumetric studies at 27 to 35 months. The neuropsychologic test and assessment regimen have been described fully (5). In summary, the Oxford grading of seizure outcome at 2 years after surgery comprises three grades: best, good, and poor. Included in best are those patients without any postoperative seizures or auras (Engel grade 1A) (6) and without neurologic deficits apart from quadrantanopia. Good includes those with occasional seizures, less than 10% of the preoperative number (Engel grades IB, ID, IIB, IID, and IIIA) (6) and without motor deficits. Poor includes all others.

Other measures of particular relevance here were, for IQ (verbal and performance), the Wechsler Intelligence Scales; for verbal memory, the logical memory passages and equivalent stories for children (7), and the Paired Associate Learning Test from the Wechsler Memory Scales forms 1 and 2; for nonverbal memory, delayed recall of the Rey figure (5); and for verbal fluency, the word association subtest of the multilingual aphasia examination (8).

The clinical and neuropsychologic outcomes at 2 years after surgery were compared with a group of 50 consecutive patients (17 left, 33 right) who had an en bloc temporal lobectomy for hippocampal sclerosis during 1983 through 1992. This group comprised 24 female and 26 male subjects with age range from 8 to 43 years and mean age of 21.3 years. The median duration of the habitual epilepsy for the ATL group at the time of surgery was 12 years (range, 3 to 26 years) compared with 12 years for the AH group. All the ATL surgeries were done by one of us (C.B.T.A.), the surgical technique being essentially as described by Falconer (9) with removal of the anterior 5 cm or so of the temporal lobe with the anterior 2 to 3 cm of the hippocampus, sparing the superior temporal gyrus on the left. The median weight of the left excision specimen was 36.5 g (range, 20.0 to 49.5 g) and 44.8 g (range, 34.5 to 57.5 g) on the right.

During 1983 through 1988 all our patients with drug-resistant temporal lobe epilepsy considered to be caused by hippocampal sclerosis who required surgical treatment underwent ATL provided that they fulfilled certain criteria based on clinical history, sphenoidal electroencephalography, cranial computed tomography, and neuropsychologic assessment, including carotid amytal testing. During

1989 we started to use AH for the majority of such patients with left-sided hippocampal sclerosis in an attempt to achieve a better neuropsychologic outcome. The criteria for deciding to operate were essentially the same for both groups.

All cranial MR examinations were performed on the same General Electric (Milwaukee, Wis) Advantage scanner operating at 1.5 T. A dedicated head coil was used in each case. Spin-echo T1-weighted sagittal images using pulse sequences of 460/11/1 (repetition time/echo time/excitations), acquisition matrix of 256 × 192, section thickness of 5 mm, and 2.5-mm gap; fast spin-echo T2-weighted axial images (5500/100 effective/1, 256 × 256 matrix, 6-mm section thickness, 2.5-mm gap); fast spin-echo dual-echo coronal images (2840/17 effective/102 effective/1, 256 × 256 matrix, 6-mm section thickness, 2.5-mm gap); and three-dimensional spoiled gradient-echo coronal images (35/5/1, 35° flip angle, 256 × 128, 1.5 mm interleaved) were routinely obtained.

The MR examinations were interpreted independently by three neuroradiologists who in particular evaluated the extent of postoperative damage and adequacy of hippocampal and amygdala resection. The length of the remaining ipsilateral atrophied hippocampus was determined, and the percentage of the remaining amygdala was assessed by visual inspection.

The preoperative and 2-year postoperative neuropsychological test scores of the left ATL and the left AH groups were compared by two-way analysis of variances: groups (left AH, left ATL) × conditions (preoperative versus 2-year postoperative) for each test condition.

TABLE 1A: Length of remaining ipsilateral atrophic hippocampus related to seizure outcome*

	Seizure Outcome Grade		
	Best	Good	Poor
Transcortical AH	8.8 ± 6.3 (n = 3)	14.0 ± 4.5 (n = 3)	10.5 (n = 1)
Transsylvian AH	14.9 ± 6.5 (n = 5)	14.5 ± 5.0 (n = 4)	18 (n = 1)
Total AH	13.0 ± 7 (n = 8)	13.7 ± 4.9 (n = 7)	14.3 ± 5.3 (n = 2)

* All values are in millimeters (mean ± SD).

TABLE 1B: The remaining ipsilateral amygdala related to seizure outcome

Seizure Outcome Grade	Amygdala Resection, %	No. of Patients
Best	80–90	6
	10	1
Good	80–90	6
	20	1
Poor	80–90	3

Results

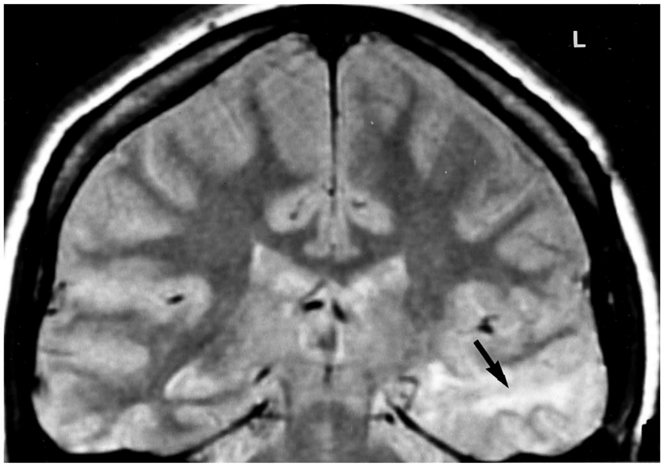
The extent of hippocampal and amygdala resection in each AH group did not seem to be directly related to seizure outcome (Tables 1A and B).

Temporal lobe damage as a result of surgery was noted to a variable degree in most cases and was more extensive in the patients operated on via the transcortical route, although there was no significant difference in patient outcome between the two AH groups.

In the transcortical AH group, MR demonstrated that the incision began 1 to 2 cm (mean, 1.3 cm) behind the anterior tip of the temporal pole. The length of the incision was 2.3 to 3.0 cm (mean, 2.5 cm). The cortex of the middle temporal gyrus and adjacent inferior temporal gyrus was thus damaged to such a distance. High signal on T2-weighted and proton-density sequences (Fig 3), consistent with gliosis, probably secondary to wallerian degeneration, was noted in white matter of the anterior temporal lobe in all these patients and involved the inferior, middle, and fusiform temporal gyri to a distance of 3.4 to 5.9 cm (mean, 4.5 cm) and the superior temporal gyrus to a distance of 2.5 to 4.2 cm (mean, 3.6 cm). There is the possibility that such damage particularly in the region of the left superior temporal gyrus might have caused an aphasic disturbance impairing language fluency, but that was not so (see below and Table 3).

In the trans-Sylvian AH group, MR demonstrated that the incision began 1.2 to 2.4 cm (mean, 1.8 cm) behind the tip of temporal pole. The length of incision was 1.5 to 2.4 cm (mean, 1.9 cm). In this group, high signal in white matter on the T2-weighted and proton-density sequences (Fig 4), probably gliosis secondary to wallerian degeneration, was detected in five patients in the anterior superior, middle, inferior, and fusiform temporal gyri to a distance of 2.4 to 4.2 cm (mean, 3.3 cm). There was no discernible secondary white matter change in five. Additional damage was noted in two patients operated on via the trans-Sylvian approach. A peri-Sylvian hematoma in one resulted in damage to the insular cortex and inferior frontal gyrus; damage to the insular cortex only was noted in another.

In nine patients (53%), high signal on T2-weighted and proton-density coronal images, consistent with wallerian degeneration, was



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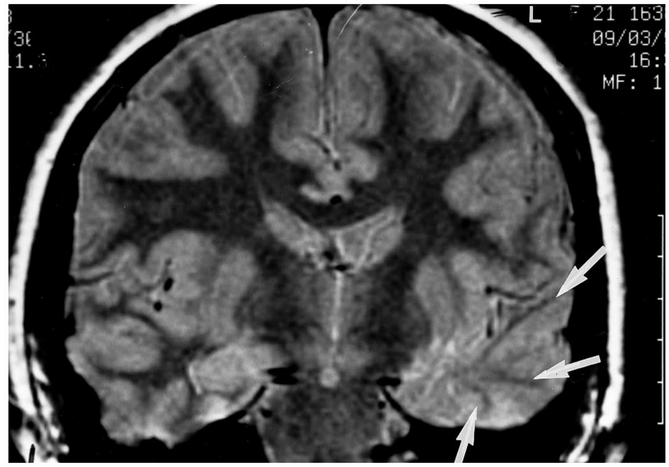

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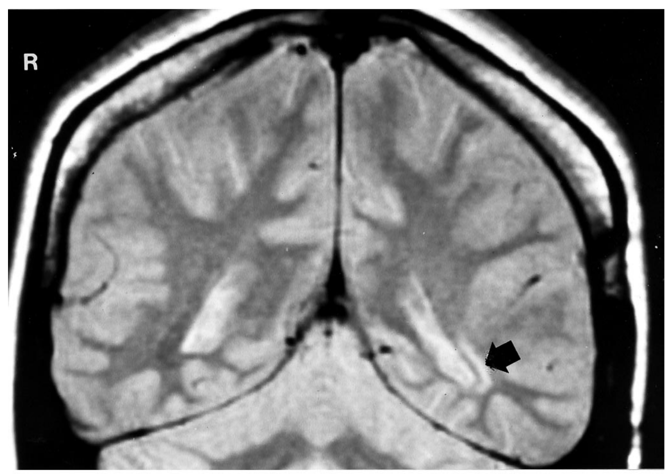
Fig 3. Fast spin-echo proton-density coronal MR image (2840/17 effective/1, 256 × 256 matrix) demonstrates high signal (*arrow*), consistent with gliosis in the white matter of the left inferior, middle, and fusiform temporal gyri after a transcortical AH.

Fig 4. Fast spin-echo proton-density coronal MR image (2840/17 effective/1, 256 × 256 matrix) demonstrates high signal, consistent with gliosis in the white matter of all gyri (*arrows*) in the left anterior temporal lobe after a trans-Sylvian AH.

Fig 5. Fast spin-echo proton-density coronal MR image (2840/17 effective/1, 256 × 256 matrix) demonstrates high signal (*arrow*) consistent with wallerian degeneration in the temporal component of the optic radiations after AH. The patient had an incomplete contralateral quadrantanopia.



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demonstrated in the optic radiations (four transcortical AH, five trans-Sylvian AH) (Fig 5). All patients had contralateral incomplete quadrantanopia. There was no case of hemianopia. In eight patients (47%), wallerian degeneration was absent (three transcortical AH, five trans-Sylvian). These patients had normal visual fields.

As for seizure cure, 2 years after AH, 47% of patients were in the best outcome group; 41% were in the good outcome group; and 12% were not improved (Table 2). This compared with 49% of comparable patients treated by en bloc temporal lobectomy who were in the best outcome group along with 33% who were in the good outcome group. The overall success rate was 88% for AH and 82% for en bloc ATL. There was no obvious difference in seizure outcome between the two AH groups.

Two years after left-sided AH there was still evidence of significantly increased verbal memory impairment since before surgery (Table 3). This was also the case with a comparable group treated with left en bloc ATL, although the extent of their deterioration was greater. Both groups had a significant rise in performance IQ over the preoperative level; the left AH group, but not the en bloc ATL group, had a significant rise in verbal IQ and improvement of nonverbal memory. Before surgery there had not been any

TABLE 2: Seizure outcome 2 years after surgery

	Grade		
	Best	Good	Poor
Right			
ATL	19	11	3
AH	2	2	
Left			
ATL	6	6	5
AH	6	6	3
Total	**33 (48%)**	**25 (36%)**	**11 (16%)**

TABLE 3: Cognition and memory (left-sided surgery only): a comparison of preoperative and postoperative status at 2 years

	AH	ATL
Verbal IQ	↑ *	
Performance IQ	↑ †	↑ †
Verbal memory	↓ *	↓ ‡
Nonverbal memory	↑ ‡	
Language (fluency)	↑ *	↑ *

Note.—↑ indicates significantly better than preoperative status; ↓, significantly worse than preoperative status.

* $P = .05$.

† $P = .001$.

‡ $P = .01$.

significant difference between the two left operation groups on any neuropsychologic measure. Too few patients underwent right-sided AH to allow valid comparisons. There was no significant difference in memory and cognition 2 years after surgery between either AH group.

Discussion

To be considered a candidate for epilepsy surgery, a patient must have disabling seizures refractory to the maximum tolerated antiepileptic medication and a localized site of seizure onset, the resection of which will not produce a significant functional deficit. The ultimate goal of epilepsy surgery is to improve the overall well being of the patient; to eliminate or reduce dramatically the frequency of seizures is only one consideration. Cognition, behavior, psychiatric dysfunction, interpersonal relationships, the ability to drive, dependency, and self-employment are others.

En bloc ATL in which the lateral neocortex and medial temporal structures are removed a standard distance posterior to the temporal pole is a safe and effective surgical treatment for intractable temporal lobe epilepsy in trained hands (see reference 10). However, it has been considered desirable that when the focus originates in the medial temporal lobe, the lateral neocortex should be preserved to limit postoperative neuropsychologic deterioration. Hence, AH was first proposed by Niemeyer in 1958 (2) and repopularized by Wieser and Yasargil in 1984 (11). There is controversy, however, as to when the procedure is indicated.

Our 2-year postoperative assessment indicates that seizure outcome is similar for AH and ATL, and our results for AH compare favorably with those quoted in the literature (1–3, 12–14). Others have found AH and ATL to be similarly effective in terms of seizure cure (12, 15). It is reported that patients have better neuropsychologic and psychosocial outcomes after AH than ATL (1, 14) but this is controversial (16, 17). The reason for controversy regarding postoperative changes in memory and cognition may be related to the length of time between surgery and assessment. The relative contributions of the medial structures and the lateral neocortex to memory are not fully understood but probably both have a role.

Although assessment early in the postoperative period suggested that AH conferred no advantage over ATL (4), later postoperative assessment suggests that left AH was significantly superior to ATL in terms of verbal IQ and nonverbal memory gains but not significantly different in terms of performance IQ and language (fluency). Verbal memory declined after both surgeries but to a greater extent after ATL. It is interesting to note that both surgeries resulted in a decline in verbal memory. It has been suggested that verbal memory is dependent on both the medial temporal lobe structures and the lateral neocortex (18), and therefore it is possible that damage to the white matter of the anterior temporal lobe after AH has resulted in impaired lateral neocortical function.

The aim of AH is reportedly to remove the amygdala, anterior hippocampus, parahippocampal gyrus, and the subiculum, which acts as a hyperexcitable fringe and hence as an amplifier. The entire amygdala, however, is not removed in practice. It is not an easily accessible structure, and the amount removed on any occasion is difficult to judge during surgery. At least 10% is reported to remain medially where it abuts the striatum, anterior commissure, and tail of the caudate (3). Additionally, it is recommended that the posterior hippocampus (at the level of the ascending tail), beyond the beginning of the P-3 segment of the posterior cerebral artery, is usually left behind. Dissection posterior to the posterior rim of the cerebral peduncle risks damage to the lateral geniculate body and the geniculocalcarine radiations of Meyer. Contrary to a previous report (13) that stated that in general, the larger the resection, the better the outcome, we have not found that seizure outcome is dependent on the extent of removal of the amygdala or hippocampus (see Tables 1A and B). It might suffice to resect most of the epileptogenic focus together with disruption of the anterior commissure and uncinate fasciculus, which are the main propagation pathways in mesiolimbic seizures.

We have demonstrated that damage to the anterior temporal lobe might be more extensive than previously recognized after transcortical and trans-Sylvian AH. It is reported that inevitably after trans-Sylvian AH (1), there is some injury to the superior temporal gyrus to a length of the incision 15 to 18 mm (ie, 20% of the length of the temporal stem), and similarly the connection areas of the superior, middle, and inferior temporal gyri within the mesiobasal temporal pole are compromised by subpial suction of the amygdala and anterior hippocampus. However, 80% of the temporal stem is generally considered untouched. In this study, abnormal signal in the white matter consistent with wallerian degeneration and gliosis was noted in 45% of the temporal lobes operated on after transcortical AH and, to a lesser extent, after trans-Sylvian AH, although this was not associated with a significant difference in patient outcome. White matter change was not demonstrated in five patients after trans-Sylvian AH. The reason is not clear. It is likely, however, that changes would have been observed in the T2 relaxation times or magnetization transfer, had these been measured in this study, because there was no difference in patient outcome between the two AH groups.

The trans-Sylvian AH is associated with increased morbidity caused by vascular complications; a moderately large peri-Sylvian hematoma was demonstrated in one patient (11% of the trans-Sylvian AH group) with resultant damage to the left insular cortex and inferior frontal lobe. We found that 53% of patients (four transcortical AH, five trans-Sylvian AH) had visual field defects in the form of contralateral incomplete quadrantanopia. This is a reported complication in 50% to 70% of ATL (see reference 10). It has been suggested that visual field defects occur in AH because of spasm affecting branches of the anterior choroidal artery supplying the optic tract and lateral geniculate body (1, 3). This is an unlikely explanation, because after actual surgical obliteration of the anterior choroidal artery for parkinsonism, visual field defects were very uncommon (see reference 19).

It is well documented that the most anterior part of the optic radiation passes alongside the anterior aspect of the temporal horn (19–22). Hence, it is surprising that temporal lobe surgery does not always produce an incomplete quadrantanopia, and therefore the degree to which the optic radiations extend forward in the temporal lobe must vary from patient to patient (23). In the patients previously reported (1, 14), field defects were conspicuously absent. We have observed that the temporal horn tip is located 2.5 to 3.0 cm behind the anterior temporal pole (unpublished observations). Given that their incision is 1 to 2 cm in length (1, 3), lateral to the M1 and anteromedial to the M2 segments, it is difficult to understand how they can avoid the optic radiations in all patients. We acknowledge that ours is a small study to try to examine critically the effects of epilepsy surgery on brain structure and patient outcome. It may be that alternate methods of AH are superior to either route described. A well-organized large multicenter trial is long overdue to determine the effects of surgery in those patients with medically intractable seizures to determine which operation is appropriate and when.

Conclusion

Transcortical and trans-Sylvian AH cause more secondary damage to the anterior temporal lobe than was previously realized. The extent of amygdala or hippocampal resection does not seem to be directly related to seizure outcome. The resection path also transects the optic radiations in some but not all patients, probably reflecting individual variation in the anterior sweep of the temporal component of the optic radiations.

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