Hippocampal ^1H -MRSI correlates with severity of depression symptoms in temporal lobe epilepsy

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Abstract—Objective: To investigate the association of an indicator of hippocampal function with severity of depression symptoms in temporal lobe epilepsy. **Methods:** We evaluated 31 patients with video/EEG-confirmed temporal lobe epilepsy using creatine/*N*-acetylaspartate ratio maps derived from a previously validated ^1H magnetic resonance spectroscopic imaging (^1H -MRSI) technique at 4.1 T. We also assessed depression symptoms, epilepsy-related factors, and self-perceived social and vocational disability. We used conservative nonparametric bivariate procedures to determine the correlation of severity of depression symptoms with imaging and clinical variables. **Results:** The extent of hippocampal ^1H -MRSI abnormalities correlated with severity of depression (Spearman rho = 0.65, p value < 0.001), but other clinical factors did not. **Conclusion:** The extent of hippocampal dysfunction is associated with depression symptoms in temporal lobe epilepsy and may be a more important factor than seizure frequency or degree of disability.

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Depression is a common comorbid condition in many neurologic disorders and appears to have an increased prevalence in community¹ and tertiary² samples of persons with epilepsy. Depression contributes to poor health outcomes^{2–5} and increased health care costs in epilepsy.^{6,7} Although few studies have evaluated the association of depression with specific epilepsy syndromes, temporal lobe epilepsy is frequently implicated.³ Involvement of the limbic^{8–10} or ventral prefrontal^{11,12} structures is a possible explanation of the increased prevalence of depression in temporal lobe epilepsy, but the influence of regional brain dysfunction as opposed to social and psychological factors is not known.¹³ To evaluate the contribution of potential neuronal and psychosocial factors to depression in temporal lobe epilepsy, we determined the association of severity of depression symptoms with the extent of ^1H magnetic resonance spectroscopic imaging (^1H -MRSI) hippocampal abnormalities, clinical variables, and self-perceived disability.

Methods. Patients. We studied a sample of adult patients who met the following criteria: 1) having had a diagnosis of temporal lobe epilepsy confirmed by recorded seizures during video/EEG monitoring, 2) capable of completing self-report questionnaires, 3) agreeing with and signing an informed consent document approved by our institutional review board (IRB), and 6) age 17 years or older. This lower age limit was used because the mood and health outcome variables had not been tested for reliability

and validity in children and adolescents. Study questionnaires were administered by the study coordinator (M.V.) and were completed by patients in a private setting, usually in the outpatient neurology clinic.

Magnetic resonance spectroscopic imaging acquisition and analysis. All adult patients undergoing presurgical evaluation for refractory temporal lobe epilepsy at the University of Alabama at Birmingham during the study period were offered ^1H -MRSI through a National Institute of Neurologic Disorders and Stroke-supported protocol (NS033919).¹⁴ Details of the imaging protocol and examples of subject ^1H -MRSI maps can be found in earlier publications.^{14–17} The subjects in the current study were a convenience sample who agreed to undergo ^1H -MRSI and were able to obtain transportation at a time when the MR scanner was available. Briefly, all studies were performed in the interictal state, using a 4.1-T whole-body imaging/spectroscopy system and a quadrature-driven, tunable, matchable head coil. Sagittal and transverse scout images were acquired using inversion recovery gradient echo sequence (TR [repetition time]/inversion recovery time [TIR]/echo time [TE] 2,500/1,000/15). The transverse images were angulated to be parallel to the long axis of the hippocampi and used to select a rectangular region of interest (ROI) in the temporal lobes that included both hippocampal regions. Water- and lipid-suppressed spectroscopic images were acquired using a TR of 2,000, TE of 50 msec, a field of view of 240 × 240 mm, and 32 × 32 phase encodes with a slice thickness of 1 cm. Nominal voxel size was 0.5 cc. Scanning was not performed in the immediate postictal state.

Data from the subjects' ^1H -MRSI were analyzed by a MR physicist (J.H.) without knowledge of the clinical, mood, or EEG data. The creatine (Cr)/*N*-acetylaspartate (NAA) metabolite ratio maps were produced by automated NMR1 (Tripos, Syracuse, NY) fitting of spectra. The normal hippocampal Cr/NAA value acquired in 20 normal healthy volunteers was 0.72 ± 0.14 . Approximately five to six pixels were placed along the length of the hippocampus and two to three across the width. We compared the Cr/NAA ratio in

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Figure 1. An example of a ^1H magnetic resonance spectroscopic imaging ratio map in a patient with mesial temporal lobe epilepsy. The map of the region of abnormality was determined by inclusion of all voxels within the hippocampi that had an abnormal creatine/N-acetylaspartate ratio defined as >2 SDs beyond normal. The degree of elevation of Cr/NA is color coded and corresponds to the abnormal ratios; values of 1.3 to 1.6 by increments of 0.1.

every voxel within the hippocampi, and those that were 2 SDs higher than normal were tagged as abnormal. The extent of abnormal voxels is a surface measurement (square millimeters), excluding voxels containing the cerebellar vermis, using software developed by our group.¹⁵ An individual patient ratio map image is presented in figure 1.

Clinical and mood assessments. All mood, seizure, clinical, and social and vocational disability assessments were performed as part of a protocol supported by the National Institute of Neurological Disorders and Stroke (NS001794), and approved by our IRB.¹⁸ Onset of epilepsy was defined as the age at the second unprovoked, nonfebrile seizure. For the purpose of the logistic regression analysis, employment was defined as working for a salary more than 20 hours per week; homemakers and students were also included in this category. Education was classified as years in a formal educational program of any type.

We used the method of seizure classification recommended by the International League Against Epilepsy.¹⁹ Subjects used monthly calendars to record seizure occurrences. After each type of seizure was identified and classified through interviews by the epileptologists, a letter was used to designate each seizure type (i.e., simple partial, complex partial, or generalized tonic-clonic) for the patient calendars. The seizure variable was coded and analyzed as a continuous variable based on the number of each seizure type per month.

The Work/Driving/Social scale of the Quality of Life in Epilepsy Inventory-89 (QOLIE-89) was designed to assess the negative impact of vocational disability, driving restrictions, and social isolation from the patients' perspective. The test-retest reliability was 0.86 and Cronbach's α was also 0.86 for the scale, as defined in a large ($n = 304$), prospective multicenter study of psychometric characteristics.²⁰ Factor analysis of the 18 subscales showed that the Work/Driving/Social scale was one of four scales in the

Table 1 Demographic and clinical characteristics of the study sample of patients with video/EEG confirmed temporal lobe epilepsy

Clinical characteristics (n = 31)	
Gender, F/M, %	55/45
Race (white/black/other), %	90/10/0
Mean (SD) age, y, at evaluation, y	35.4 (10.8)
Mean (SD) age at epilepsy onset, y	15.0 (12.0)
Mean (SD) years of education	13.1 (2.1)
Employment	
Employed (>20 hr/wk, includes homemaker or student), no. (%)	15 (49)
Unemployed (0–20 hr/wk), no. (%)	16 (51)
No. (%) of antiepileptic drugs	
1	10 (33)
2	17 (55)
3	4 (12)
Mean (SD) no. of seizures/mo	14.7 (17.0)
Patients with simple partial seizures, no. (%)	15 (48)
Patients with complex partial seizures, no. (%)	27 (87.5)
Patients with generalized tonic-clonic seizures, no. (%)	11 (34)

epilepsy-targeted composite factor, as opposed to mental health, cognition, or physical health factors. The scale score ranges from 0 to 100, with higher scores indicating better self-perceived functioning.

Mood status was determined by the Depression scale of the Profile of Mood States (POMS). The POMS is a checklist of adjectives describing six mood conditions. The instrument has undergone extensive reliability and validity testing in a variety of samples of patients with chronic illness and healthy subjects^{21,22} and including previous studies of epilepsy patients.^{18,23–25} The depression subscale has been validated through extensive psychometric testing and is scored 5-point Likert scale for which higher values indicate greater mood disturbance.^{21–23}

Statistical analysis. We used Spearman ρ correlations to determine the bivariate association of the ^1H -MRSI variable and each clinical variable with the POMS Depression scale. After Bonferroni adjustment for multiple comparisons in the bivariate analyses, significance was set at $p < 0.01$. We also applied linear regression analysis to evaluate the independent associations of the predictive variables with severity of depression symptoms. All analyses were performed using SPSS version 10.0 (www.SPSS.com; Chicago, IL).

Results. Patient characteristics. Demographic and seizure characteristics of the 31 subjects are shown in table 1. All subjects had at least one complex partial or generalized tonic-clonic seizure in the previous 3 months at the time of evaluation. Ten (32%) patients were on one antiepileptic medication, 17 (55%) were on two medications, and four (13%) were on three medications.

Correlation of depressive symptoms, ^1H -MRSI, and clinical variables. The scatterplot comparing POMS Depression scale scores with the extent of the abnormal ^1H -MRSI Cr/NAA ratio maps is shown in figure 2. The results of bivariate nonparametric correlation analyses are presented in table 2. No association with laterality

Figure 2. Correlation of severity of depression symptoms with spatial extent of hippocampal dysfunction defined by ^1H magnetic resonance spectroscopic imaging creatine/*N*-acetylaspartate ratio maps ($n = 31$).

of ^1H -MRSI results and depression symptoms was found, but the study was not powered to determine less than a strong association. The extent of ^1H -MRSI abnormality (Spearman $\rho = 0.65$; $p < 0.001$), but no other variables, was significantly associated with the POMS Depression scale scores. Linear regression analysis confirmed the independent association of ^1H -MRSI results ($\beta = 0.63$; $p < 0.001$) with POMS Depression scale scores, and the absence of association with other seizure or self-perceived disability variables. The model explained 57% of the variance (adjusted $R^2 = 0.57$) in the depression symptoms.

Discussion. The hippocampus is a critical component of the temporolimbic-frontal-subcortical network involved in major depressive disorders.^{26,27} Although hippocampal dysfunction in temporal lobe epilepsy might be anticipated to be associated with depression, few clinical studies have directly supported this plausible relationship. Depression symptoms are reported to be greater in temporal lobe epilepsy patients with MRI-identified mesial tempo-

ral sclerosis vs those with normal hippocampi, independent of lateralization,¹⁰ but correlation of volume reduction with severity of depression symptoms was not determined. One previous study⁹ observed that reduced hippocampal serotonin 1A receptor binding correlated with elevated depression scores, but another¹² found association only with the cingulate gyrus using a similar ligand; these differences may be explained by dissimilar analytic techniques and partial-volume effects. Two earlier investigations^{8,11} using ^{18}F -fluorodeoxyglucose (FDG)-PET scans in temporal lobe epilepsy did not demonstrate an association of depression with glucose metabolism deficits within the hippocampi.

We found a significant correlation of severity of depression symptoms with extent of voxels containing an abnormal Cr/NAA ratio in the hippocampi of persons with temporal lobe epilepsy. To our knowledge, this is the first description of a correlation of severity of depression symptoms with spatial involvement of a biomarker of neuronal dysfunction within a limbic structure. The strength of this correlation may be in part due to the high signal-to-noise ratio provided by the 4.1-T magnet, which allows smaller voxel size and precise identification of hippocampal gray matter to minimize partial-volume effects.²⁸ Also, compared to other methods of metabolic imaging, NAA may be more closely associated with the mechanisms of hippocampal dysfunction that contribute to limbic system-dependent mood disturbance. However, we could not identify other studies of hippocampal NAA using ^1H -MRSI in unipolar depression to further support this supposition.²⁹⁻³¹ Because sampling of ^1H -MRSI was limited to the temporal lobes in our study, correlation of dysfunction in other brain regions with depression symptoms cannot be determined; involvement of other components of the limbic-frontal-subcortical network in temporal lobe epilepsy remains a plausible hypothesis.

The discrepancy of our ^1H -MRSI findings with the previous reports of the lack of association of FDG-PET results with depression in temporal lobe epilepsy may be of relevance for understanding clinical correlates of metabolic deficits in the hippocampus. In a detailed comparison of ^1H -MRSI to FDG-PET in temporal lobe epilepsy, hippocampal Cr/NAA measures did not correlate with glucose metabolism; indicating that alterations in glucose uptake and NAA concentrations represent different mechanisms of cellular metabolic dysfunction.²⁸ Rate of brain glucose metabolism is largely dependent on pyramidal neuron activation and subsequent glutamate release, and recent studies indicate that glucose utilization is directly related to glia uptake of glutamate.³² The wide variability of hippocampal neuron/glia ratios commonly described in temporal lobe epilepsy¹⁷ may explain previous observations of extremes of interictal hyper- and hypometabolism in different regions in mesial temporal sclerosis.³³ This variability may also explain the lack of correlation of hippocampal

Table 2 Spearman ρ correlations of severity of depression symptoms with clinical variables in 31 patients with temporal lobe epilepsy

Variables	Spearman ρ	p
^1H -MRSI	0.65	<0.001
Duration of epilepsy	0.17	0.37
Work/driving/social scale*	-0.23	0.22
GTC seizure rate	-0.05	0.23
Gender	-0.17	0.37
Complex partial seizure rate	-0.12	0.52
No. of antiepileptic drugs	-0.11	0.57

* From the Quality of Life in Epilepsy Inventory (QOLIE)-89.

^1H -MRSI = ^1H magnetic resonance spectroscopic imaging;
GTC = generalized tonic-clonic seizure.

glucose metabolism with symptoms of depression. Alternatively, NAA synthesis is dependent on mitochondrial enzymes, including L-aspartate N-acetyltransferase, and coenzyme A, which may be more sensitive to clinically significant limbic dysfunction in temporal lobe epilepsy than is glucose-dependent basal energy maintenance. It should be recognized that postictal effects of seizures and chronic effects of antiepileptic drugs could confound the results of imaging of metabolic variables in epilepsy patients.

Previous investigations suggest that increased Cr/NAA ratios in temporal lobe epilepsy are not due solely to cell loss in the hippocampus.¹⁷ Atrophy is an unlikely explanation of our findings because we evaluated the extent of abnormal Cr/NAA ratios in voxels within the hippocampi. Decreased NAA is associated with cerebral regions of interictal spiking and seizure onset,^{34,35} which in combination with our results suggests the plausible hypothesis that depression symptoms in temporal lobe epilepsy may be due to the influence of hyperexcitable hippocampal neurons on the limbic network.

The role of the hippocampus in depression is not clearly defined, although recent investigations have identified hippocampal abnormalities.²⁶ Hippocampal volumes are found in most studies to be smaller in neurologically normal patients with a history of depression compared to euthymic controls.²⁷ Results of functional imaging studies, predominantly FDG-PET, are less consistent in the hippocampus during major depressive episodes, but the hippocampus has been less thoroughly investigated than the amygdala and ventromedial frontal cortex.^{26,36} Putative mechanisms of injury include chronic exposure to cellular stressors, including corticotropin-releasing factor and cortisol. An investigation of 17 patients receiving long-term corticosteroid therapy found abnormal Cr/NAA ratios in the medial temporal region as well as greater depression rating scores vs normal controls; these findings suggest that chronic exposure to elevated corticosteroid levels could induce dysfunction in limbic structures and subsequent depression.³⁷ Additional data are necessary to more fully understand the role of the hippocampus in the genesis and maintenance of clinical depression, especially in specific neurologic disorders such as epilepsy.

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NeuroImages

Figure 1. Preoperative (upper) and postoperative (lower) images document chronic reversible Kernohan notch brainstem compression.

Reversible Kernohan notch

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A 55-year-old patient experienced episodic headaches, left facial twitching, and increasing falls over 2 years. Multiple yearly

Figure 2. Histology confirmed an arachnoid cyst.

brain MRs (figure 1, top panels) revealed a large right frontal arachnoid cyst with evolving contralateral brainstem notching against the left tentorium^{1,2} (tentorial arrows, figure 1, top panels). The lesion was marsupialized into the Sylvian fissure. Histology confirmed an arachnoid cyst (figure 2). Postoperatively, the patient's symptoms abated, remaining asymptomatic after 1 year. MRI follow-up at 7 months demonstrated mild residual left peduncle gliosis with resolution of the Kernohan notch (figure 1, bottom panels).

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