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MR in Partial Epilepsy: Value of High-Resolution Volumetric Techniques

A. James Barkovich, Howard A. Rowley, and Frederick Andermann

PURPOSE: To assess the utility of high-resolution volumetric MR examinations with thin partition size for patients with simple partial epilepsies that were well located with electrical and clinical criteria. **METHODS:** Fifteen patients with normal standard MR findings were studied with three-dimensional Fourier transform volumetric MR examinations using thin (1 to 1.5 mm) partition size. Imaging was done in the coronal plane, then reformatted manually on an independent console with each gyrus analyzed in the planes parallel and perpendicular to its axis. **RESULTS:** Cortical abnormalities were detected in 8 of the 15 patients in the study. Surgical resection of the affected cortex in 2 patients showed polymicrogyria in one and dysplastic cortical organization in the other. **CONCLUSION:** In this preliminary study, 3-D Fourier transform volumetric MR examinations with thin partition size appeared to be useful in identifying cortical dysplasias in patients with localized simple partial epilepsies.

Index terms: Seizures; Magnetic resonance, 3-D; Brain, abnormalities and anomalies

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As a result of excellent contrast resolution and the lack of "beam hardening" from the overlying calvarium, magnetic resonance (MR) imaging is a superb modality for the evaluation of the cerebral cortex. In particular, areas of dysplastic cerebral cortex, such as polymicrogyria, are being detected considerably more frequently in the MR era than ever before (1–6). Moreover, patients with focal cortical dysplasia and intractable partial epilepsies are now candidates for surgical resection of the dysplastic cortex (2, 5, 7, 8). MR is valuable in the preoperative location of the dysplastic cortex in these patients (5, 7). Many patients with partial epilepsies however, have normal standard MR findings, even when the seizure focus can be located well by electroencephalography and clinical examination (6, 9). Dysplastic cortex can range from grossly dysmorphic to subtly dysmorphic (with fused gyri and minor irregularities of the cortex–white matter junction) to grossly normal with microscopic abnormalities of lamination (10–12). Therefore, it seemed likely that the use of higher-resolution imaging techniques would provide greater sensitivity in the detection of subtle areas of cortical dysplasia. We report the results of a prospective study in which patients with simple partial epilepsies and normal standard MR findings were studied with high-resolution volumetric MR examinations with thin partition size. Our goal was to determine whether subtle areas of cortical dysplasia might be detected with greater sensitivity with this technique.

Patients and Methods

Patients were selected for this study based on the following criteria: (*a*) clinical diagnosis of simple partial epilepsy; (*b*) localized electroencephalogram abnormality; (*c*) normal standard MR findings. All standard MR scans were reviewed by one of the authors to confirm the lack of cortical abnormalities. From March, 1991 to December, 1993, 15 patients who met these criteria were studied with volumetric MR examinations with thin partition size. These patients ranged from 4 to 44 years old (mean age, 17 years).

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Images were taken with a volumetric three-dimensional Fourier transform (3DFT) gradient-echo technique with radio-frequency spoilers used to eliminate steady state magnetization. Data were acquired using pulse sequences of 35/5/1 (repetition time/echo time/excitations) with θ of 35°, and a 256 × 192 acquisition matrix. A partition size of 1.5 mm (yielding a voxel size of 0.9 × 0.9 × 1.5 mm) with 124 partitions was used if coverage of the entire brain was desired. A partition size of 1.0 mm (yielding a nearly isotropic voxel size of 0.9 × 0.9 × 1.0 mm) with 60 partitions was used if only a part of the brain was studied. Imaging was done in the coronal plane, then reformatted manually on an independent console, using standard commercially available software. Images were reviewed separately by two neuroradiologists; consensus was obtained between the two in all cases.

Tissue obtained from surgical specimens was fixed in neutral buffered formalin for 3 to 6 days. Tissue blocks were embedded in paraffin and sectioned at 8 μm. The paraffin sections were stained with hematoxylin and eosin, luxol-fast blue-Klüver-Barrera, and Bielschowsky stains. Immunohistochemical studies with glial fibrillary acidic protein were also done.

Results

Clinical Manifestations

By inclusion criteria, all 15 patients had simple partial seizures. In 3 patients, the seizures began as twitching in the left side of the body, 3 in the left arm, 3 in the right leg, 2 in the right arm, 2 in the left leg, 1 in the left perioral region, 1 in the right side of the face. Secondary generalization of the seizures occurred in 6 patients. The seizure focus, as determined by an electroencephalogram, was right frontal in 5 patients, left parasagittal in 3 patients, right frontoparietal in 2 patients, left frontal in 2 patients, left parasagittal in 2 patients, and left frontoparietal in 1 patient. No difference in seizure type or electroencephalographic findings was detected between the group of 8 patients in whom MR abnormalities were ultimately discovered versus the group of 7 patients in whom no MR abnormalities were discovered.

Imaging Results

Imaging abnormalities that corresponded to the seizure focus, as detected by an electroencephalogram, were detected on the 3DFT volume images in 8 of the 15 patients. The most common finding was irregularity of the cortex–white matter junction (Figs 1 and 2), which was seen in 7 patients. In 4 of these patients, the abnormality could be appreciated only when the affected gyrus was imaged along the plane of its long axis (Fig 1). Thickening of the cerebral cortex was apparent in 4 patients, with the abnormal cortex measuring 4 or 5 mm in thickness (Fig 3). Normal cerebral cortex measures 2 to 3 mm in thickness (11).

To locate the focus of dysplastic cortex, it was necessary to page through the images in various orthogonal and oblique planes; proper analysis required viewing each gyrus parallel and perpendicular to its long axis. Some gyri that appeared somewhat thick when viewed in a plane that was oblique relative to the long axis of the gyrus could confidently be identified as normal when viewed in a plane perpendicular to the pial surface. Other questionably thick gyri were confirmed as abnormal. Still other subtle gyral abnormalities that were not obvious on standard 5-mm-thick 2DFT sequences, in particular irregularities of the cortex–white matter junction, could be detected on the volumetric 3DFT images when viewed in the proper plane.

Surgical and Pathologic Correlation

Based on clinical, electroencephalographic, and MR findings, two patients with intractable seizure disorders underwent surgical resection of the dysplastic cortex. Surgery was guided by electrocorticography in conjunction with findings of abnormal cortical texture and results of the MR study. In both cases, the cortex was resected from the area where the MR abnormality was identified. Pathologic analysis of the tissue showed polymicrogyria, with disordered cortical lamination and abnormal neuronal orientation, in one patient (Fig 1C and D) and cortical dysplasia, with disordered cortical lamination, single file neuronal arrangement, poorly defined cortical–white matter junctions, and subpial glial-neuronal heterotopia in the other (Fig 2B).

Discussion

In this study, we have shown that high-resolution MR imaging, using 3DFT volumetric techniques and thin partition size, allows improved identification of cortical gyral abnormalities if the imaging data are carefully reviewed in multiple planes that optimally show the anatomy of each individual gyrus. This result is not surprising when one considers the scope of cortical dysplasias. Frank polymicrogyria, the most ob-

Fig 1. Patient with seizures beginning with tingling in the left leg.

A, 3DFT volume image reformatted in a sagittal plane shows irregularity of the cortex–white matter junction (*arrows*).

B, Sagittal 5-mm T1-weighted image at the same location shows no definite irregularity.

C, 3DFT volume image reformatted in a coronal plane shows some cortical irregularity (*arrows*) but no definite abnormality.

D, Histologic section from resected cortex (Bielschowsky stain, magnification 250 ×) shows fusion of the molecular layers (*arrows*) of adjacent microgyri.

E, Histologic section of resected cortex (Nissl stain, 250 ×) shows lack of normal cortical lamination with abnormally oriented pyramidal cells (*small arrows*) and an abnormal number of large, dysplastic cells (*large arrows*).

vious form of cortical dysplasia on gross pathology, is fairly easily identified by MR, because the microgyri merge into a pattern of thickened cortex with irregular outer and inner surfaces (2). Most of the cortical abnormalities described by pathologists in dysgenetic cortex, however, are much more subtle. These subtle anomalies include leptomeningeal glioneuronal heterotopias, fusion of adjacent gyri, cortical bundles of myelin, multinucleated cortical neurons, cortical "balloon" cells, heterotopic nodules, single-file neuronal radial patterns, neuronal clustering, increased number of neurons, misalignment/disorientation of neurons, abnormal cortical lamination, and irregularity of the cortical–white matter junction (12). Although most of these abnormalities are cryptic to the radiologist (and will likely remain so until MR microscopy becomes clinically useful), we were able to detect subtle cortical thickening or irregularities of the cortical–white matter junction in more than half the patients in this study. Thus, we feel that careful analysis of the 3DFT data significantly improves the ability to identify subtle cortical irregularities as compared with standard 2DFT techniques.

Identification of subtle areas of cortical dysplasia is a time-consuming endeavor, because each gyrus must be individually analyzed. To perform this analysis properly, the image must be rotated such that the plane of analysis is perpendicular to, and then parallel to, the section of gyrus being analyzed. Relatively small obliquities of the plane of analysis with respect to the gyrus in question can result in apparent gyral thickening and a false-positive result. In each patient in this study, the analysis of the 3DFT images required between 35 and 90 minutes of physician time at an independent workstation. The time increased and the yield diminished with the amount of brain studied. Therefore, this technique is likely to be more useful for patients with a seizure focus that is well-located with both clinical and electrical criteria. Because patients with well-located epilep-

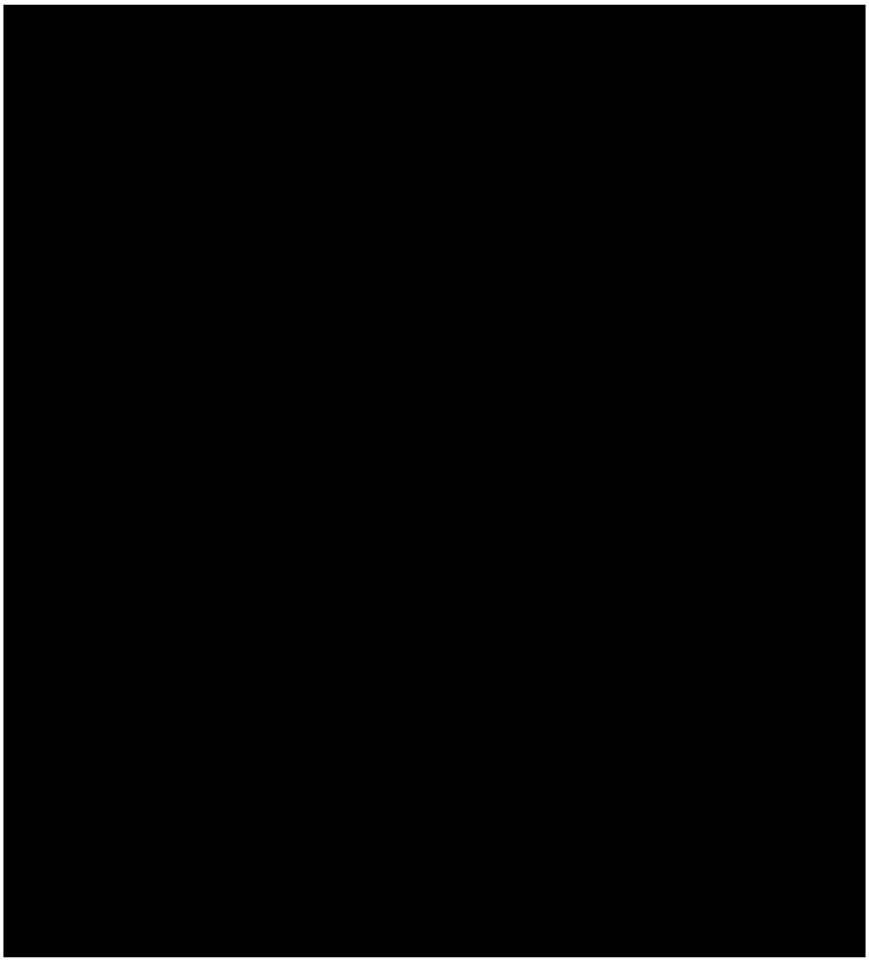

Fig 2. Patient with seizures beginning in the left perioral region.

A, Sagittal reformation from 3DFT volume acquisition shows irregularity (*arrows*) of the cortex–white matter junction in the anterior insular cortex (gyrus breves insulae).

B, Routine 5-mm-thick sagittal spin-echo image does not show the cortical abnormality.

C, Histologic section of resected cortex (Nissl, 25 ×) shows disordered cortical lamination, single-file neuronal arrangement, poorly defined cortical–white matter junctions, and subpial glial-neuronal heterotopia.

togenic foci are also the best candidates for surgical therapy if medical therapy fails (7, 9), it is reasonable to restrict this technique to such patients. Nonetheless, methods to automate analysis of the cortical gyral pattern are presently under investigation.

We selected patients with simple partial seizures for this study because the seizure focus is best defined in this population, particularly when the clinical manifestations are motor or sensory. We suspect that the yield of the MR study would be lower if the location of the seizure focus were not as well defined, for reasons alluded to above: the longer the imaging physician analyzes the brain, the poorer his or her concentration will be. In all likelihood, the yield

Fig 3. Patient with seizures beginning in the right arm.

A, Coronal 3DFT image shows cortical thickening and irregularity of cortical–white matter junction (*thin arrows*) in the posterior left insular cortex. A focus of heterotopic gray matter (*thick arrow*) is noted incidentally in the peritrigonal region on the right.

B, Coronal 5-mm T2-weighted spin-echo image shows no apparent difference in the insular cortex of the right and left hemispheres.

of the exam will diminish as the concentration of the analyst falters from fatigue. In such cases, an automatic detection program may prove to be particularly valuable.

Only two of the eight patients with abnormal 3DFT MR findings in this study have undergone surgery and, therefore, pathologic proof of dysplastic cortex is available in only those two patients. Of the other six patients, three are controlled well enough by medications that surgery has not been recommended at present, one has more than one abnormal electrical focus, and two have refused surgery. One of the patients refusing surgery had a temporal lobectomy, without relief of symptoms, before the availability of the 3DFT technique. Only after the surgery was the epileptogenic focus located in the frontoparietal region; irregularity of the cortex–white matter junction was then detected by the high-resolution MR technique. Despite the lack of surgical confirmation in the remaining patients, the correlation with the clinical and electrical location, as well as the similarity of the imaging appearance on their studies with that on the surgically proven studies, allows us to be confident of our diagnoses.

To summarize, standard 2DFT MR imaging techniques can show gross anomalies of neuronal migration and cortical organization in a large number of affected patients. In patients with more subtle cortical anomalies, however, higher-resolution techniques are required. Our preliminary data suggest that volume 3DFT techniques, now available on most commercial MR scanners, can show some of these subtle dysplasias if thin partition size is used and the resultant data are carefully analyzed. The major drawback of this technique is that it is very physician-intensive and requires considerable time.

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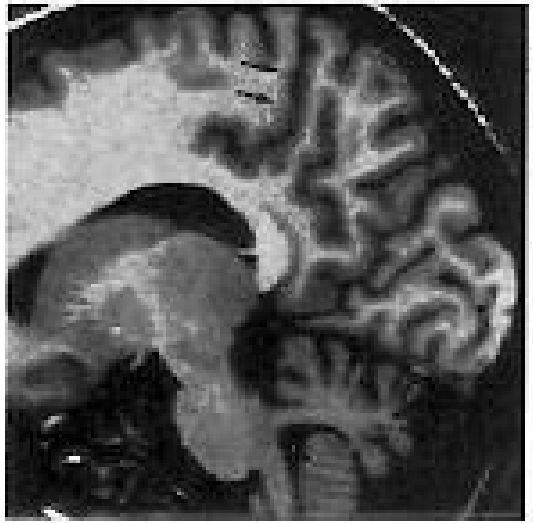

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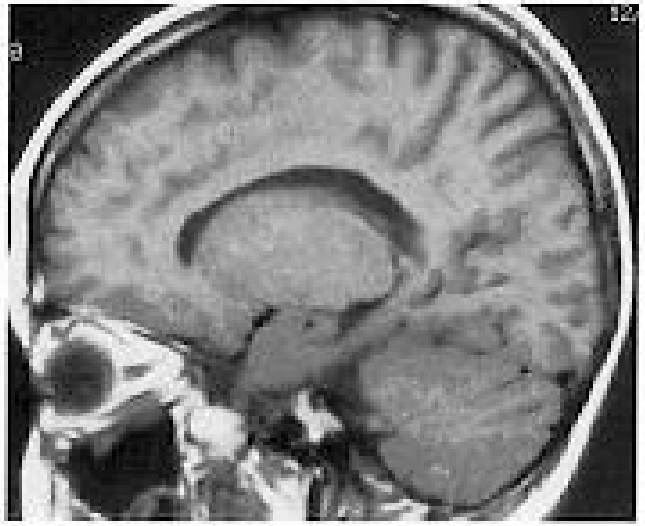

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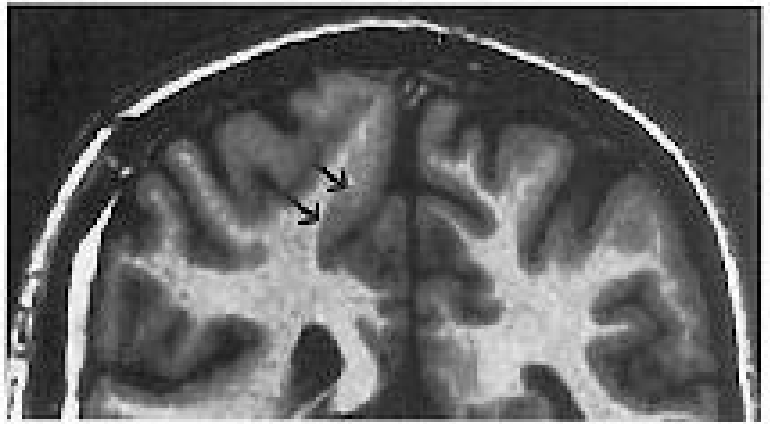

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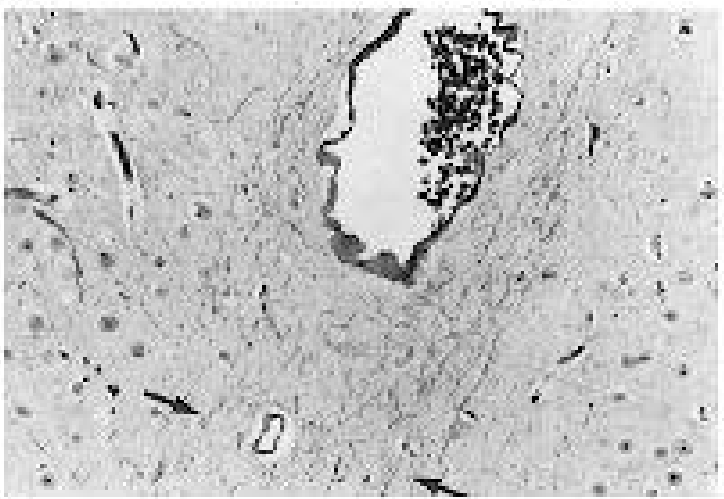

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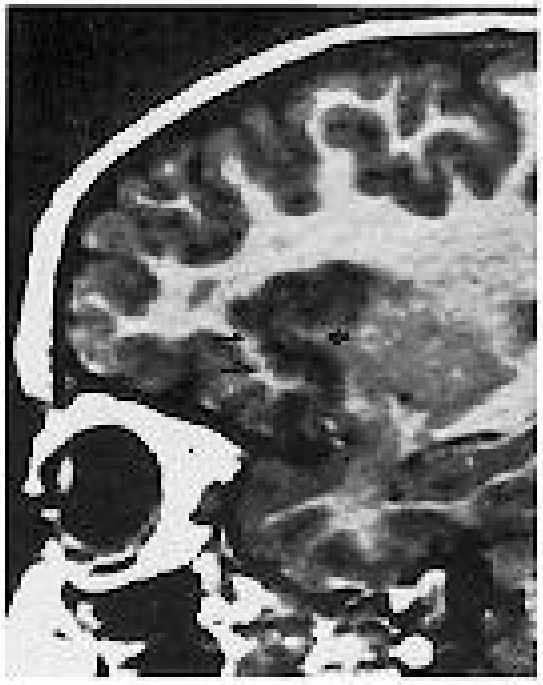

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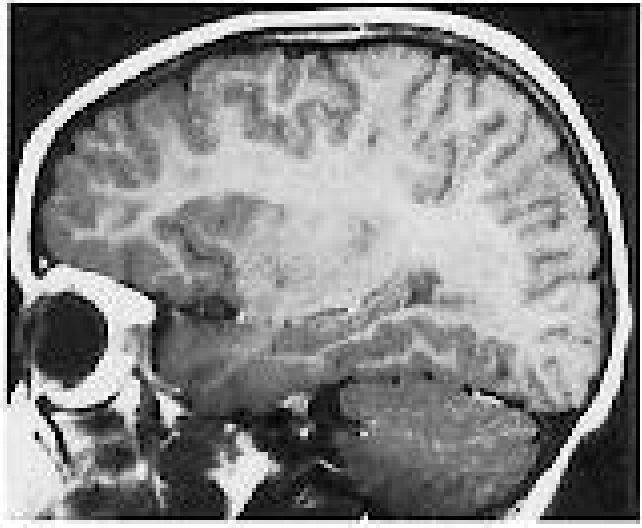

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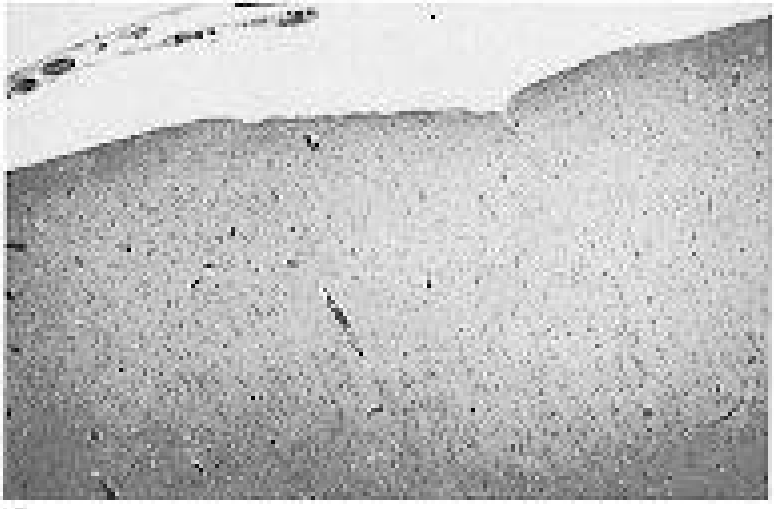

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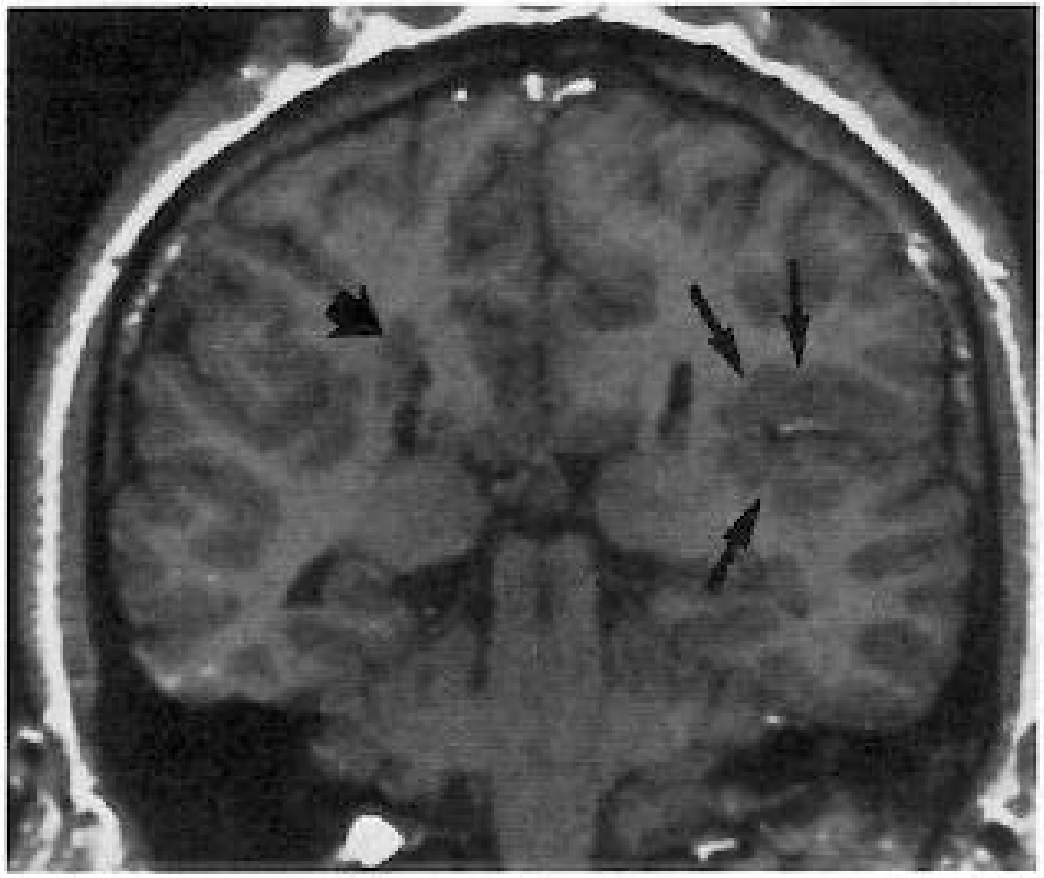

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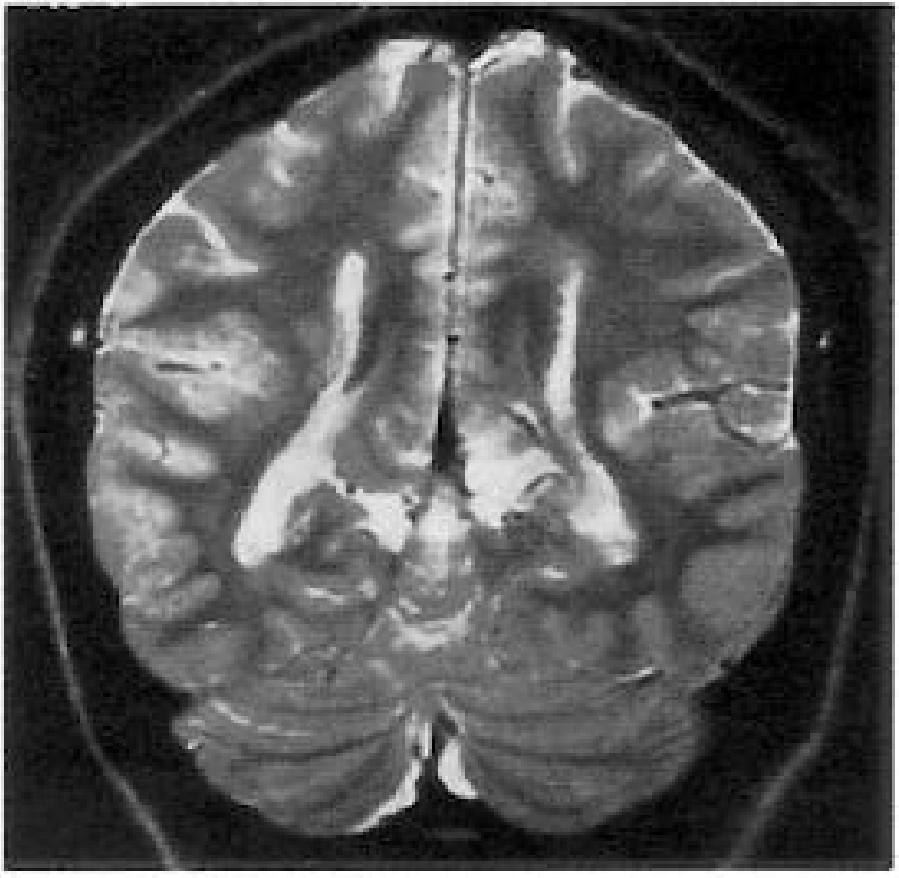

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