ORIGINAL ARTICLE

Seven-Tesla MRI of Hippocampal Sclerosis
An In Vivo Feasibility Study With Histological Correlations

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Introduction: Temporal lobe epilepsy (TLE) is the most frequent form of focal epilepsy in adults. Because approximately half of these patients develop drug resistance, epilepsy surgery designed to remove the epileptogenic zone is an excellent option in selected patients. Histopathological analyses of hippocampal specimens in TLE patients revealed 4 types of Ammon's horn sclerosis, which are correlated with long-term epileptological outcome. The aim of this study was the correlation of noninvasive, high-resolution, morphological magnetic resonance imaging (MRI) at an ultra-high-field (7 T) of the hippocampus in TLE patients with histopathological findings.

Methods: High-resolution, T2-weighted FSE MRI in 14 patients with drug-resistant temporal lobe epilepsy was performed on a 7-T Magnetom using a 32-channel coil. Four independent investigators assessed the delineation and semiquantitative evaluation of volume, signal intensity, internal architecture, and overall grading of the hippocampal subfields CA1-4, as well as the presence of the dentate granule cell layer (DGCL), on MRI scans. Results were compared with semiquantitative evaluation of neuronal loss and astrogliosis in the histological sections of the surgical specimens.

Results: Seven-tesla MR examinations were evaluable in 13 cases. Volume loss and signal intensity, as well as overall grading, showed a strong correlation between MRI and histology in individual CA regions. Furthermore, sensitivity and specificity values up to 100% were found for the detection of pathology in the CA subfields. The prediction of Ammon's horn sclerosis type was correct in up to 12 of 13 cases, whereas the dentate gyrus could not be delineated on MRI.

Discussion: High-resolution, ultra-high-field MRI is a promising tool for the detection of subtle changes in the hippocampus in patients with temporal lobe epilepsy. Large cohorts will be necessary to confirm the predictive value of 7-T MRI in the preoperative evaluation of TLE patients.

Key Words: 7-T MRI, temporal lobe epilepsy, hippocampal sclerosis

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Temporal lobe epilepsy is the most common type of epilepsy in adults. Approximately 50% of patients become refractory to drug treatment during the course of their disease. Epilepsy surgery designed to remove the epileptogenic zone is an excellent treatment option in these cases. Up to 80% of patients who undergo this surgery become seizure-free in the long term.[1]

Temporal lobe epilepsy is characterized by clinical, electrophysiological, histopathological, and radiological hallmarks. The histopathological changes detected in approximately 60% of hippocampal specimens, that is, neuronal loss and reactive astrogliosis, are summarized as Ammon's horn sclerosis (AHS). Recently, 4 types of AHS were recognized by the International League Against Epilepsy (ILAE). Although AHS ILAE type 1 is associated with a good epileptological outcome, the absence of AHS (noAHS) predicts unfavorable outcomes after surgery.[2] In addition, pathological changes of the dentate granule cell layer (DGCL) have been correlated with neurocognitive decline in temporal lobe epilepsy (TLE) patients.[3]

Neuronal loss and reactive astrogliosis can also be visualized on magnetic resonance imaging (MRI). Hippocampal volume loss, hyperintensity on T2-weighted sequences, and loss of the internal architecture of the hippocampus (HC) are the hallmark features that can be assessed on 3.0-T MRI.[4–8] However, a detailed analysis of hippocampal subfields and the dentate gyrus cannot be achieved due to the relatively low resolution in routine clinical MRI at 1.5 T and 3.0 T.

This drawback was overcome by the introduction of ultra-high-field (UHF) MRI scanners. The higher signal-to-noise ratio (SNR) at 7 T results in a higher spatial resolution within the same measurement time compared with 3 T. This higher spatial resolution allows the evaluation of the internal hippocampal structure, including the distinction of the CA subfields, and enhances the delineation of the DGCL, which has already been shown in vitro[9,10] as well as in vivo.[11,12] Whole-body 7-T MR scanners have already translated these advantages into the clinical setting. Clinically feasible scanning times of up to 10 minutes per sequence and a reduction of artifacts close to the skull base were established by optimized protocols.[13–16]

These developments suggest the usefulness of 7-T MRI during the preoperative planning phase in temporal lobe epilepsy patients. The prediction of the histological type of AHS and DG pathology, and thus, the possible postoperative epileptological outcome, would influence decision making before surgery and aid in advising patients during the informed consent process.

The aim of this study was, therefore, to evaluate volume and signal changes on preoperative 7-T MRI in patients who were undergoing surgery for temporal lobe epilepsy and to correlate these data with the histopathological findings of the extent of neuronal loss and reactive astrogliosis in the hippocampal subfields. The type of AHS, based on the ILAE classification, was also assessed as a possible preoperative predictive marker.

MATERIALS AND METHODS

A total of 17 patients who were scheduled for epilepsy surgery due to temporal lobe epilepsy were included in this study (for clinical details, see Table 1).

High-resolution imaging was performed on a 7-T Magnetom (Siemens Healthineers, Erlangen, Germany) with a 32-channel head

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TABLE 1. Patient Characteristics

ID	Age, y	Sex	Duration of Epilepsy, mo	Side of Surgery	Type of Surgery	ILAE AHS Type (Histology)
1	48	F	58	Left	sAHE	ILAE type 1
2	55	M	461	Left	sAHE	ILAE type 1
3	52	M	586	Right	AMTR	ILAE type 1
4	34	F	120	Left	sAHE	ILAE type 1
5	29	M	60	Right	sAHE	ILAE type 1
6	43	M	396	Right	sAHE	ILAE type 1
7	33	M	77	Right	AMTR	ILAE type 2
8	39	F	156	Right	AMTR	ILAE type 2
9	24	M	47	Right	AMTR	no AHS
10	31	F	60	Right	AMTR	no AHS
11	35	F	120	Left	AMTR	no AHS
12	44	M	492	Left	AMTR	no AHS
13	36	M	168	Right	AMTR	no AHS

ILAE, International League Against Epilepsy; AHS, Ammon's horn sclerosis; sAHE, selective amygdalohippocampectomy; AMTR, anteromedial temporal resection.

coil (Nova Medical). A T2-weighted 2D fast spin echo (FSE) sequence was obtained in a paracoronal, hippocampal plane perpendicular to the central sulcus (matrix, 688 × 688; FOV, 230 × 172.5; image resolution, 0.33 × 0.33 × 1.5 mm; slices, 25; parallel imaging, 2; repetition time [TR], 4500 milliseconds; echo time [TE], 81 milliseconds) with an acquisition time of 8:48 minutes.

From the 15 patients who underwent epilepsy surgery, 14 specimens that included the hippocampus could be collected. Two patients refused surgery ultimately, and a disconnective procedure was performed in 1 patient.

Coronal T2-weighted FSE images were evaluated by 4 independent raters, all qualified neuroradiologists (with 22, 25, 10, and 7 years of experience). Image quality was semiquantitatively rated (0 = excellent, 1 = good, 2 = poor, 3 = not evaluable). Hippocampal anatomy was evaluated bilaterally at 3 levels, that is, at the level posterior to the corpora mamillaria, anterior to the nucleus ruber, and posterior to the nucleus ruber. For this study, only the middle level on the operated side was considered for statistical evaluation to enable correlation with histology. A semiquantitative evaluation of volume (V; 0 = no volume loss, 1 = moderate volume loss, 2 = severe volume loss), signal intensity (I; 0 = no signal intensity changes, 1 = hyperintense signal, 2 = severely hyperintense signal), and internal structure (S; 0 = no loss of internal structure, 1 = moderate loss of internal structure, 2 = severe loss of internal structure) was performed, and a grading score was assigned to each of the CA subfields (G; 0 = no changes, 1 = moderate changes, 2 = severe changes). Furthermore, the appearance of the granule cell layer (GCL) of the dentate gyrus was graded (0 = not visible, 1 = likely visible, 2 = clearly visible).

Semiquantitative scores of grading, volume, signal intensity, and internal structure were simplified to binomial ratings (0 = not evident, 1 = evident) and averaged, resulting in scores between 0 and 1. Values of 0.5 or above were defined as positive.

Histopathological evaluation was performed according to the ILAE consensus paper on AHS.[2] Formalin-fixed, paraffin-embedded tissue was stained for anti-NeuN (MAB377, clone A60, 1:100, EMD Millipore, Darmstadt, Germany) and anti-GFAP (M0761, clone 6 F2, 1:500, Dako, Glostrup, Denmark) according to established routine protocols. Neuronal loss (0 = no neuronal loss, 1 = moderate neuronal loss, 2 = severe neuronal loss) and astrogliosis (0 = no astrogliosis, 1 = moderate astrogliosis, 2 = severe astrogliosis) were quantified. Furthermore, alterations of the DGCL were noted (0 = no alterations, 1 = layer thinning, 2 = bilamination, dentate granule cell (DGC) islands, DGC spreading).

Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated for each investigator, with Microsoft Excel 2016 (Microsoft Inc, Redmond), and are given as average values. Descriptive statistics, correlation analyses, and χ^2 values were calculated using IBM SPSS Statistics 22 (IBM Deutschland GmbH, Ehningen, Germany). Spearman correlation coefficient was used to demonstrate relationships between radiological and histological evaluation.

RESULTS

Of the 17 patients included in this study, hippocampal specimens and 7-T MRI scans suitable for further assessment were available from 13 (5 female, 8 male). Mean age at surgery was 38.7 years (±9.2 years) with a mean duration of disease of 18.0 years (±16.2 years).

In 5 patients, a selective amygdalohippocampectomy (sAHE) was performed, whereas the other 8 patients were scheduled for an anteromedial temporal resection (AMTR). Surgery was undertaken on the left side in 5 cases, and on the right side in 8 cases.

Electroencephalographic findings and side of surgery matched in all patients. Lateralization on 7 T was possible in up to 8 of 13 cases. All of these 8 cases showed AHS at histological evaluation, whereas the remaining 5 cases did not show AHS on histopathological evaluation.

In all of these 5 MRI-negative patients, an AMTR was performed. Of these, 4 patients were operated on the right side.

The diagnosis of hippocampal sclerosis was confirmed in 8 patients, with ILAE type 1 in 6 and ILAE type 2 in 2 cases.

Evaluability of 7-T MRI Scans

The quality of 7-T MRI scans was rated as not assessable in 1 of the 14 cases, which was excluded from all investigations. In the remaining 13 patients, excellent evaluability was assigned in 49% (Fig. 1), whereas "well evaluable" and "still evaluable" were chosen in 23.5% and 27.5%, respectively (Table 2).

Correlation Studies Of the CA Sectors

In the CA1 sector, there was a positive correlation between the MR-based grading of G ($r = 0.790$, $P < 0.001$), V ($r = 0.818$, $P < 0.001$), I ($r = 0.490$, $P < 0.001$), and S ($r = 0.592$, $P < 0.001$) and the histological grading of sclerosis. Furthermore, there was a positive

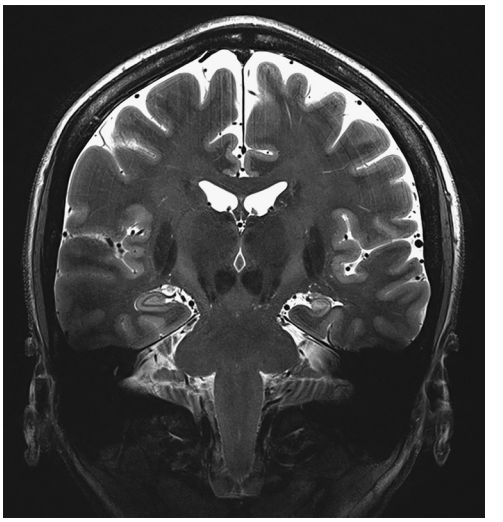

FIGURE 1. T2-weighted coronal whole-brain image from a patient with left temporal lobe epilepsy and a histological diagnosis of AHS type 1 acquired at 7 T (corresponding to detail image D; ID 4).

TABLE 2. Semiquantitative Rating of 7-T Image Quality Per Investigator

Investigator	Excellent	Good	Poor
1	8 (62%)	2 (15%)	3 (23%)
2	6 (50%)	3 (25%)	3 (25%)
3	6 (46%)	3 (23%)	4 (31%)
4	5 (38%)	4 (31%)	4 (31%)
Mean	49.0%	23.5%	27.5%

correlation between G ($r = 0.553$, $P < 0.001$), V ($r = 0.572$, $P < 0.001$), S ($r = 0.544$, $P < 0.001$), but not I, and the histological grading of astrogliosis based on GFAP staining.

There was a positive correlation between G ($r = 0.474$, $P < 0.001$), V ($r = 0.630$, $P < 0.001$), and S ($r = 0.404$, $P < 0.001$), but not I, and the histological grading of sclerosis in the CA2 sector. A negative correlation between I ($r = -0.281$, $P = 0.046$), but not G, V, or S, was seen with the histological grading of astrogliosis.

In CA3, there was a positive correlation between G ($r = 0.759$, $P < 0.001$), V ($r = 0.653$, $P < 0.001$), I ($r = 0.528$, $P < 0.001$), and S ($r = 0.760$, $P < 0.001$) and the histological grading of sclerosis, and a negative correlation between I ($r = -0.486$, $P < 0.001$), but not G, V, or S, and the grading of astrogliosis.

In the CA4 sector, there was a positive correlation between G ($r = 0.742$, $P < 0.001$), V ($r = 0.561$, $P < 0.001$), I ($r = 0.489$, $P < 0.001$), and S ($r = 0.760$, $P < 0.001$) and the histological grading of sclerosis. In addition, there was a negative correlation between the MR-based evaluation of G ($r = -0.528$, $P < 0.001$), I ($r = -0.732$, $P < 0.001$), and S ($r = -0.605$, $P < 0.001$), but not V, and GFAP grading.

Sensitivity and Specificity Analysis

When averaged between the 4 investigators, changes in the hippocampal subfield CA1 could be correctly predicted by 7 T MRI, with a sensitivity, specificity, as well as PPV and NPV of 100%. In CA2, sensitivity and NPV remained at 100%; however, specificity declined to 68.3% and PPV to 50%. Alterations of the CA3 subfield were detectable with a sensitivity of 92.9% and a specificity of 83.3%, and a PPV and NPV of 86.6% and 92.9%, respectively. In addition, pathologies in CA4 were detectable with a median sensitivity of 85.7% and a specificity of 83.3% with PPV and an NPV of 85.7% each (for details, see Table 3).

Visibility Of the Granule Cell Layer of the Dentate Gyrus on 7 T

When all investigators were considered together, the GCL of the dentate gyrus was seen in a total of 29 cases, and not detectable in 22 cases. However, a normal or even wide GCL could be assigned from histological evaluation in 39 cases, whereas a narrow GCL was seen in only 12 cases. There was no correlation between visibility of the GCL on 7 T and changes in histological evaluation. Most importantly, the GCL was not visible on 7 T in 17 cases with a normal histological pattern. Overall specificity was 56.5%, with a sensitivity of 41.7%.

Types of Hippocampal Sclerosis at 7 T Based on the ILAE Classification

The presence or absence of hippocampal sclerosis was correctly detected with a specificity of 80% to 100% and a sensitivity of 75% to 100%, depending on the investigator. All but 1 investigator yielded sensitivity and specificity values of 100%, respectively.

None of the investigators reported the type of hippocampal sclerosis correctly in all cases (Table 4). Investigator 1 diagnosed noAHS correctly in 4 of 5 histologically proven cases, whereas, in the remaining noAHS case, a type 2 was assessed on MRI. Two cases were defined as MRI-negative despite histological changes of type 1 and type 2. Type 1 was correctly detected in 5 of 6 cases, whereas, in 1 case, a noAHS was assigned on MRI. Type 1 was incorrectly assigned to 1 case of AHS type 2 (χ^2 [4] = 8.09, $P = 0.088$).

Investigator 2 reported noAHS correctly in 5 of 5 cases. Type 1 was correctly assigned in 6 of 6 cases, whereas, in one type 2 case, a type 1 was mistakenly seen on MRI (χ^2 [2] = 12.00, $P = 0.002$).

Investigator 3 was correct in 5 of 5 cases with noAHS, and in 6 of 6 cases with type 1 (χ^2 [2] = 12.00, $P = 0.002$). Type 3 and type 1 were incorrectly reported in 2 cases of type 2 AHS (χ^2 [4] = 18.57, $P = 0.001$).

Investigator 4 diagnosed noAHS correctly in 5 of 5 cases, and type 1 in 5 of 6 cases. In 1 case with AHS type 1, a type 3 was assigned

TABLE 3. Detailed Description of Sensitivity, Specificity, PPV, and NPV for Each Investigator

		Investigator 1	Investigator 2	Investigator 3	Investigator 4
CA1	Sensitivity	75.0%	100%	100%	100%
	Specificity	100%	100%	83.3%	100%
	PPV	100%	100%	87.5%	100%
	NPV	71.4%	100%	100%	100%
CA2	Sensitivity	100%	100%	100%	100%
	Specificity	70.0%	66.7%	70.0%	50.0%
	PPV	50.0%	50.0%	50.0%	37.5%
	NPV	100%	100%	100%	100%
CA3	Sensitivity	85.7%	100%	85.7%	100%
	Specificity	100%	83.3%	83.3%	83.3%
	PPV	100%	85.7%	85.7%	87.5%
	NPV	85.7%	100%	83.3%	100%
CA4	Sensitivity	85.7%	100%	85.7%	85.7%
	Specificity	100%	66.7%	83.3%	83.3%
	PPV	100%	75.0%	85.7%	85.7%
	NPV	85.7%	100%	83.3%	83.3%

PPV, positive predictive value; NPV, negative predictive value.

TABLE 4. Type of AHS by Investigator Compared With the Histological Result

ID	ILAE Type (Histology)	Investigator 1	Investigator 2	Investigator 3	Investigator 4
1	ILAE type 1	Type 1	Type 1	Type 1	Type 1
2	ILAE type 1	Type 1	Type 1	Type 1	Type 1
3	ILAE type 1	Type 1	Type 1	Type 1	Type 1
4	ILAE type 1	Type 1	Type 1	Type 1	Type 1
5	ILAE type 1	Type 1	Type 1	Type 1	Type 3
6	ILAE type 1	noAHS	Type 1	Type 1	Type 1
7	ILAE type 2	Type 1	—	Type 1	Type 1
8	ILAE type 2	noAHS	Type 1	Type 3	Type 1
9	noAHS	noAHS	noAHS	noAHS	noAHS
10	noAHS	noAHS	noAHS	noAHS	noAHS
11	noAHS	noAHS	noAHS	noAHS	noAHS
12	noAHS	noAHS	noAHS	noAHS	noAHS
13	noAHS	Type 2	noAHS	noAHS	noAHS

ILAE, International League Against Epilepsy; noAHS, absence of AHS.

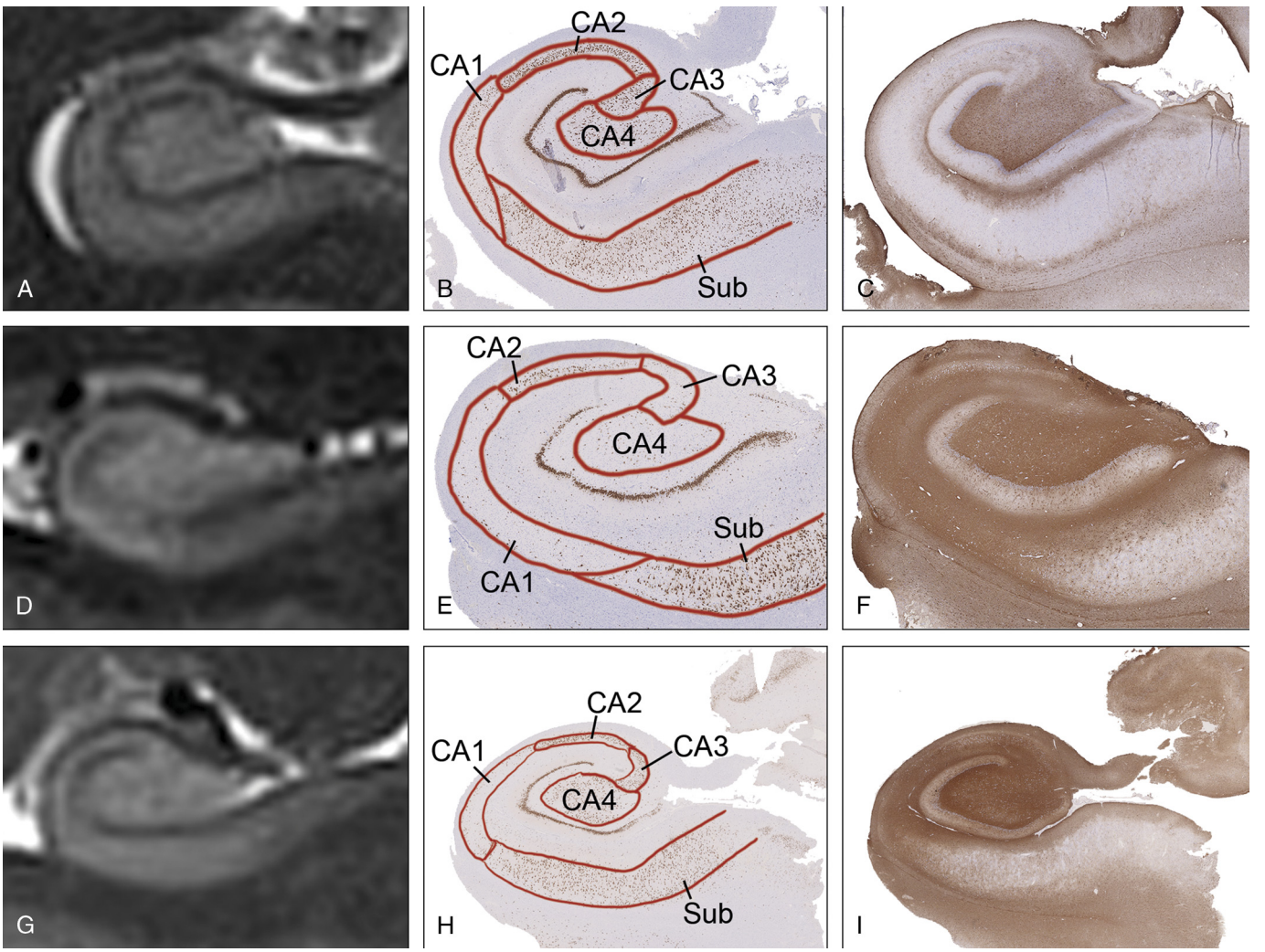

FIGURE 2. Features of hippocampal sclerosis, as evaluated histologically (NeuN, GFAP), can also be seen on 7 T MRI. NoAHS (A–C; ID 9) is characterized by sustained primary neurons in the CA regions (B) and no-to-mild astrogliosis (C), whereas the internal structure of the hippocampus is maintained on MRI (A). In AHS type 1 (D–F; ID 4; mirrored for a clearer arrangement and better comparability), most of the CA subfields, except CA2, are devoid of neurons (E), whereas reactive astrogliosis is prominent in these areas (F). A hyperintense signal on T2-weighted images, as well as a complete loss of the internal architecture is evident on MRI (D). In AHS type 2 (G-I, ID 8), the CA1 subfield is predominantly affected by neuronal loss. A hyperintense signal on corresponding MRI images is seen in the CA1 region (G), whereas neuron loss (H) and astrogliosis (I) are observed on histology. Figure 2 can be viewed online in color at www.investigativeradiology.com.

on MRI. The 2 cases of AHS type 2 were misdiagnosed as type 1 on MRI (χ^2 [4] = 13.62, P = 0.009) (Fig. 2).

DISCUSSION

The estimation of surgical outcome in temporal lobe epilepsy is currently based on clinical characteristics, such as initial precipitating injuries, that is, a history of febrile seizures, traumatic brain injury, perinatal asphyxia, meningitis, or a brain tumor, or the presence of AHS at histopathological evaluation.[1] Four histological types of AHS have been recognized by the ILAE, and they are each associated with distinct epileptological postoperative outcomes.[2] Although a tentative clinical-pathological correlation has been proposed, the predictive value of any neuropathological classification would be dependent on a presurgical/imaging characterization of the pathological changes.[5] Thus, we performed an in vivo feasibility study comparing high-resolution 7-T MRI with histopathological slides from TLE patients with and without AHS and were able to predict the type of AHS in up to 11 of 13 cases.

In clinical practice, preoperative evaluation includes imaging of the mesial temporal lobe on 1.5- or 3-T MR scanners, where the superiority of 3 T compared with 1.5 T, with regard to anatomical details and volumetric analyses, has been shown in many studies.[5–7,17]

However, imaging of the hippocampus at 1.5, as well as 3 T, is often limited by low spatial resolution and poor tissue contrast. Ultra-high-field MRI scanners operating at 7-T static magnetic field strength provide a better SNR, which scales linearly with the field strength, thus producing high-resolution images of the investigated anatomical structures.[12,18–20] Depending on the protocol used, resolutions of up to 100 μm, with a slice thickness of 0.7 to 3 mm, can be achieved on T2-weighted gradient and FSE images. Clinically unacceptable long measurement times and susceptibility artifacts, especially near the skull base or next to pneumatized structures, hindered the evaluation of the mesial/inferior temporal lobe in humans in the early development stages of UHF MR systems. However, recent studies have proven that sequence protocol optimization, improvement of FSE techniques at 7 T, and improved

multi-array head coil development at 7 T may, at least in part, help to overcome susceptibility artifacts at the skull base and significantly shorten scan times while providing high spatial resolution.[13,21]

In our series, 1 patient had to be excluded from the analysis due to poor image quality. More than 70% of the remaining MR studies were at least "well assessable." Although 30% were determined as "still assessable" by the raters, a higher percentage of high quality scans at 7 T without distorsions would be necessary for the clinical setting. However, in this study, the 7 T scans were performed directly after a 3 T scan in the same patient due to scheduling reasons. Because UHF strength MRI in vivo is more prone to artifacts due to vascular pulsatility, patient movement, proximity of the structures of interest to the bony skull base, and distortions at air-tissue interfaces, a longer time in the scanner may increase these artifacts, and therefore, decrease image quality. Furthermore, the gantry of the 7-T scanner is narrower compared with 3-T scanners, which is a practical drawback for adipose or claustrophobic patients.

In formalin-fixed hippocampi scanned ex vivo, UHF MRI provides a very detailed anatomical depiction of its internal structures,[9,10] including the pyramidal cell layer of the hippocampal subfields CA1 to CA4. Furthermore, the microvasculature, as well as subtle functional changes in blood flow, may be visualized.[22]

Based on this detailed anatomical visualization of the internal HC structures, subtle changes at very early phases of disease can be detected by UHF MRI. In addition to pathological changes associated with mesial temporal sclerosis,[19] high-field MRI is expected to be able to detect other potentially epileptogenic lesions, such as focal cortical dysplasia,[18] or small vascular malformations, such as cavernoma.[23–25] The extent and type of histopathological changes have also been shown to vary in the longitudinal axis of the hippocampus.[26] As the surgical specimens available for histopathological analysis usually encompass only a small portion of the hippocampus along its rostro-caudal axis, the possibility to classify histopathological subtypes on preoperative 7 T MRI will enhance our understanding of the disease process. In addition, the detection of bilateral hippocampal pathology and its severity is improved. The prerequisite for drawing conclusions from 7-T MRI is the correlation of radiological and histological data, which we were able to demonstrate in terms of neuronal loss/astrogliosis and volume loss/signal intensity changes/loss of internal structure.

Lateralization of the epileptogenic zone in 7-T MRI was accomplished in all of our cases with histologically proven AHS in this study. Furthermore, the type of AHS was correctly predicted in 11 of 13 cases. However, the number of patients with AHS types other than type 1 and noAHS was low in our study. A more frequent representation of AHS types 2 and 3 would have been difficult to accomplish because the prevalence is relatively low and would require a very large epilepsy surgery series.[2] Accuracy in evaluation of the hippocampal subfields varied between investigators, represented by differences in sensitivity and specificity. This is, on one hand, attributable to the small cohort, resulting in rather big differences when only 1 or 2 subjects are rated differently, on the other hand, to the different experience of the investigators in rating 7-T MRI scans. Overall, CA2 was the least consistently assessed subfield: on its cranial margin, a small vessel was observed in some patients—most likely a branch of the intrahippocampal arteries or sulcal veins—which led to a partial volume effect in this region, impeding the evaluability of signal intensity, volume, and internal architecture. However, it was suggested that higher field strengths allow for more consistent and easier delineation of hippocampal subfields.[27,28]

Only a few studies on 7-T MRI of the hippocampus of patients with temporal lobe epilepsy have been published thus far.[10,18,19] Volumetric analysis, with regard to the variation of the internal structure of the HC along its longitudinal axis, have shown that atrophy in epilepsy patients is highly specific to the AHS, mostly sparing the dentate gyrus. Furthermore, digitations of the hippocampal head were missing or reduced, compared with healthy control subjects. Partial loss of hippocampal striation, detected by changes in the white matter neighboring the vestigial sulcus, could be demonstrated.[19,29] The comparison of healthy and sclerotic HC in epilepsy patients also showed marked hippocampal atrophy, represented by mild to moderate hyperintensity on T2-weighted images in the sclerotic HC.[4]

After the acquisition of our 7 T in vivo data, a study was published that focused on the evaluation of AHS by 7-T MRI ex vivo. Hippocampal specimens were formalin-fixed and agarose-embedded, and then scanned ex vivo in a 7-T MRI unit with long (not precisely defined) acquisition times. Different layers of the hippocampus were discernible on 7-T imaging, but the boundaries between the CA subfields and the GCL of the dentate gyrus could not be differentiated. The suggested use of diffusion-weighted images and measurement of fractional anisotropy (FA) for the differentiation of AHS types should be considered in future studies.[10] Two findings in patients with AHS are in accord with a hallmark key feature used in our study—loss of internal structure: increased mean diffusivity, which the authors suggested was indirectly due to an expansion of the extracellular space in which water molecules move following neuronal cell death, and decreased FA, likely related to pathologic shrinkage and fiber alteration. Based on the latter, fiber-tracking revealed a general disorganization of the reconstructed fibers.

One of the major obstacles that needs to be overcome in vivo is the need for long acquisition times that are required to achieve high-resolution images that allow discrimination of the substructures of the hippocampus.[30] In our study, patients were subjected to a sequence of approximately 15 minutes in the 7-T scanner, which also seems reasonable for clinical practice. Technical advances may allow for accelerating acquisition times, whereas enhancing the level of detail in 7-T MRI scans in the future.

CONCLUSIONS

We could demonstrate the feasibility of 7-T MRI in the clinical setting in patients with temporal lobe epilepsy. Good image quality made the delineation of hippocampal subfields possible with a very good correlation with AHS histopathological changes. However, the dentate gyrus could not be evaluated in detail. The evaluation of a large series of patients scheduled for epilepsy surgery will be necessary to prove the value of UHF MR in the preoperative prediction of AHS type in TLE patients, which is indicative of the clinical outcome.

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