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1.5 versus 3 Tesla structural MRI in patients with focal epilepsy

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ABSTRACT

Objective. Structural MRI is a critical component in the pre-surgical investigation of epilepsy, as identifying an epileptogenic lesion increases the chance of post-surgical seizure freedom. In general practice, 1.5T and 3T MRI scans are still the mainstream in most epilepsy centres, particularly in resource-poor countries. When 1.5T MRI is non-lesional, a repeat scan is often performed as a higher-field structural scan, usually 3T. However, it is not known whether scanning at 3T increases diagnostic yield in patients with focal epilepsy. We sought to compare lesion detection and other features of 1.5T and 3T MRI acquired in the same patients with epilepsy.

Methods. MRI scans (1.5T and 3T) from 100 patients were presented in a blinded, randomized order to two neuroradiologists. The presence, location, and number of potentially epileptogenic lesions were compared. In addition, tissue contrast and the presence of motion/technical artifacts were compared using a 4-point subjective scale.

Results. Both the qualitative tissue contrast and motion/technical artifacts were improved at 3T. However, this did not result in statistically significant improvement in lesion detection. Qualitatively, five patients had subtle lesions seen only at 3T. However, minor differences in image acquisition parameters between 1.5T and 3T scans in these cases may have resulted in greater lesion visibility at 3T in four patients. Based on a general linear model analysis, the presence of a focal abnormality on EEG was predictive of the presence of a lesion at 1.5T and 3T.

Significance. Repeat MRI scanning of patients with focal epilepsy at 3T using similar scan protocols does not significantly increase diagnostic yield over scanning at 1.5T; the increased signal-to-noise ratio can potentially be better allocated for novel scan sequences in order to provide more clinical value.

Key words: MRI, focal epilepsy, epilepsy surgery, EEG

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Epilepsy is one of the most common neurological diseases, affecting over 50 million people worldwide, with an estimated prevalence of 0.5% [1]. Approximately 60% of epilepsy patients have focal epilepsy, in whom seizures arise from a single brain region [2]. Approximately 30% of these patients have seizures that cannot be controlled by anti-seizure drugs [2, 3]. For these people, surgical removal of the epileptogenic zone must be considered. Unfortunately, seizure cure is achieved in less than 50% of these patients due to incomplete identification and removal of the seizure-generating tissue [4-6]. Structural MRI is a critical component in the pre-surgical investigation of epilepsy, owing to its ability to identify epileptogenic lesions that may be

potential targets for epilepsy surgery [7]. Indeed, the odds of being seizure-free after surgery is 2.5 times greater if a lesion is identified [6].

A typical clinical seizure MRI protocol includes T1- and T2-weighted, fluid-attenuated inversion recovery (FLAIR), and a 3D volume acquisition sequence. Notably, technical differences (*e.g.*, slice thickness, interslice gaps) could potentially impact lesion detection [8-10]. Given this, the Neuroimaging Task Force of the International League Against Epilepsy now recommends a set of sequences, termed the HARNESS protocol, with three-dimensional volumetric acquisitions at its core (T1 and FLAIR) to maximize lesion detection [11]. Currently, many centres operate both clinical 1.5T as well as 3T scanners, and research scanners with fields strengths of 7, 9.4 or 11.7T. Higher field strengths (3T and higher) produce images with greater signal-to-noise ratios (SNR) but have an increased risk of generating artifact [12]. There is an increasing trend towards using clinical scanners with higher-field strengths (*e.g.*, 3T vs 1.5T) in the light of findings from previous studies [13-15]. However, these prior studies primarily compared lesion detection in a non-blinded manner and rarely in a clinical context. These studies are helpful in showcasing improved image quality at higher-field strengths with increased SNR. However, an important question that has not been adequately addressed is whether MRI scans at higher magnetic field strengths actually increase diagnostic yield in patients with focal epilepsy in a clinical setting. This is important to consider for patients undergoing epilepsy presurgical evaluations in resource-poor communities with limited access to MRI scanners.

In this study, we assessed the utility of increased field strength of scans in a multidisciplinary scenario where the MRI scan is viewed in combination with other relevant clinical information, thus mimicking a real-world clinical scenario. With this in mind, we compared lesion detection, tissue contrast, technical artifact, and motion artifact using seizure protocol MRI scans acquired at 1.5T and 3T.

Material and methods

This study was approved by the University of Calgary Research Ethics Board. We identified all patients from the adult and paediatric epilepsy clinics and Seizure Monitoring Units of the University of Calgary Comprehensive Epilepsy Program who underwent a 3T seizure-protocol scan from 2002 to 2014. The clinical and medical imaging history of each patient was reviewed and inclusion criteria were: i) a diagnosis of focal epilepsy and ii) at least one readable 1.5T and one readable 3T structural MRI scan. Exclusion criteria included no epilepsy diagnosis and a diagnosis of generalized epilepsy. We included all patients with focal epilepsy rather than only those with drug-resistant epilepsy.

Subjects were scanned on 1.5 and 3T scanners in Calgary, using a standard epilepsy protocol (*table 1*). All 3T scans were performed using the same scanner located at the Seaman Family MR Research Centre, whereas the majority of 1.5T scans were obtained using clinical scanners in Calgary. Three scans were performed outside Calgary. For any patient with multiple 1.5 and 3T scans, the two scans separated by the least amount of time were chosen to minimize any changes related to disease progression or aging. Two neuroradiologists carried out an independent review of all images using PACS workstation that

▼ **Table 1.** Typical MR seizure protocols employed at 1.5T and 3T.

Sequence	1.5T	3T
Axial FSE T2	3mm thk, 0mm sp; TE 94, ET 15, TR 3880, matrix 512 × 288, FOV 230 × 172.5mm	3mm thk, 0mm sp; TE 100.6 , ET 24, TR 5619, matrix 512 × 448, FOV 220 × 220mm
Axial FLAIR	3mm thk, 0mm sp; TE 93, ET 15, TR 9120, matrix 256 × 134, FOV 230 × 172.5mm	3mm thk, 0mm sp; TE 125.9, ET 1, TR 8452, matrix 228 × 224, FOV 240 × 240mm
Coronal FSE T2 through temporal lobes	3mm thk, 0mm sp; TE 72, ET 19, TR 3160, matrix 5132 × 224, FOV 200 × 175mm	3mm thk, 0mm sp; TE 106.8, ET 23, TR 7856, matrix 512 × 384, FOV 220 × 220mm
Coronal FLAIR through temporal lobes	3mm thk, 0mm sp; TE 94, ET 15, TR 8000, matrix 256 × 168, FOV 200 × 175mm	3mm thk, 0mm sp; TE123.2, ET 1, TR 8828, matrix 352 × 224, FOV 220 × 220mm
Axial 3D MP-RAGE or FSPGR	1mm thk, 0mm sp; TE 2.89, ET 1, TR 1950, matrix 256 × 192, FOV 256 × 192mm	1mm thk, 0mm sp; TE 3.2, ET 1, TR 8.184, matrix 256 × 256, FOV 250 × 250mm

ET: echo train; sp: spacing; TE: echo time; thk: thickness; TR: relaxation time. All times (TE, ET, TR) are in msec.

contained the patient's clinical scans (Impax version 6.0, Agfa) with real-time multiplanar reformation capabilities. Neuroradiologist JS had 13 years of practice at the time of reading the images and AH had two years of practice. The reformation allowed for the nearly isovoxel examination of the 3D T1 MP-RAGE images, making it possible to better identify malformations of cortical development even in orthogonal planes. To simulate an epilepsy pre-surgical workup, results from other investigations were made available to the neuroradiologists, following a standard protocol in our epilepsy centre. These investigations included EEG, positron emission tomography (PET), interictal and ictal single-photon emission tomography (SPECT), and consensus reports from our weekly epilepsy program surgical conference rounds. If surgery was performed, however, both viewers were blinded to the surgical outcome and any post-resection investigations, but not the presurgical investigations. The anonymized clinical information provided to reviewers were succinctly summarized to avoid recall bias.

Each of the 200 MRI datasets (100 patients scanned at 1.5 and 3T) were presented to each neuroradiologist separately and in a semi-random order, in which datasets were presented in a random order without considering order of field strength presentation but with the stipulation that 1.5 and 3T scans from the same patient were not presented consecutively in order to minimize recall bias. The average number of scans reviewed between reviewing 1.5 and 3T scans in the same patient was 74, with a range of 7 to 190 scans. Thus, while the scanner field strength could be apparent from inspection of the scans, this randomization procedure prevented the direct comparison of a 1.5 to 3T scan from the same patient and also masked recall bias.

The radiologists were asked to assess the scans for three features: tissue contrast, motion/technical artifacts, and presence of lesions. Tissue contrast was rated on a 4-point scale (1 = poor delineation of grey to white matter; 4 = excellent delineation). The presence of motion/technical artifacts that degrade the quality of the image was rated on a 4-point scale (1 = frank and disruptive artifacts, 4 = no visible artifacts). Lastly, the presence, location, and number of potentially epileptogenic lesions were identified. In the case of disagreement between the reviewers for a given scan, the images were reviewed by a third imaging expert (PF) and a consensus agreement was achieved. We reviewed EEG reports and video-EEG monitoring reports and compared the location of focal interictal or ictal abnormalities in each case to the lobe where an MRI abnormality was seen (if present) at 1.5 and 3T. An EEG abnormality was considered focal when it was restricted to a lobe as per the nomenclature used in the international 10-20 system. In instances where the involvement was restricted to contiguous channels on the EEG, but involving two lobes (*e.g.*, frontotemporal), as per channel nomenclature, the lobe of maximum involvement was determined by analysing phase orientation on bipolar montage or analysing amplitudes on a common average referential montage [16]. We chose interictal EEG to perform the predication analysis as most of our patients were outpatients and did not undergo video-EEG monitoring at any time.

Data were analysed using a mixed-modelling approach (or random intercepts model) using the R Statistical software package (R Development Core Team, https://www.R-project.org). This was used to fit a logistic regression of lesion detection, as predicted by magnet strength and reviewer, taking into account a number of other factors.

Results

A total of 114 patients were initially identified for inclusion into the study. Seven patients were excluded from the study: six were determined to not suffer from focal epilepsy (psychogenic non-epileptic seizures [*n*=4] and generalized epilepsy [*n*=2]) and one patient did not have sufficient clinical information available. Seven more potential patients were eliminated from the study as their 1.5T scans were no longer available. Ultimately, 100 patients (66 male; median: 31 years; IQR: 21 years) were analysed. Eighty-four patients initially underwent a 1.5T scan with a median interscan interval of 1.9 years (IQR: 3.56 years; 52 male; median: 31 years; IQR: 20 years). Sixteen patients initially underwent a 3T scan with a median interscan interval of 1.2 years (IQR: 3.6 years; 12 male; median: 34 years; IQR: 19 years).

Five patients (5%) had lesions detected at 3T that were not seen at 1.5T, as summarized in *figure 2* and *table 2*. Notably, in three of the five cases (Patients 1-3), slight technical differences between 1.5T vs 3T were present (smaller interslice gaps at 3T) which may have increased the chance of detecting subtle changes at 3T. In addition, one patient (Patient 5) had a heterotopic nodule that was identified at 3T but not at 1.5T. On review of this case, the lesion was also visible at 1.5T, although not as clearly (*lower panel of figure 1, figure 2*). Notably, in this case, there were also slight technical differences between the scans (thinner slices and narrower interslice gaps at 3T) which may have increased the chance of detecting the subtle lesion.

Table 2 provides a summary of the clinical data of the six patients in whom differences were observed between the 1.5 and 3T scans. Of these patients, MRI produced unique localizing information about a

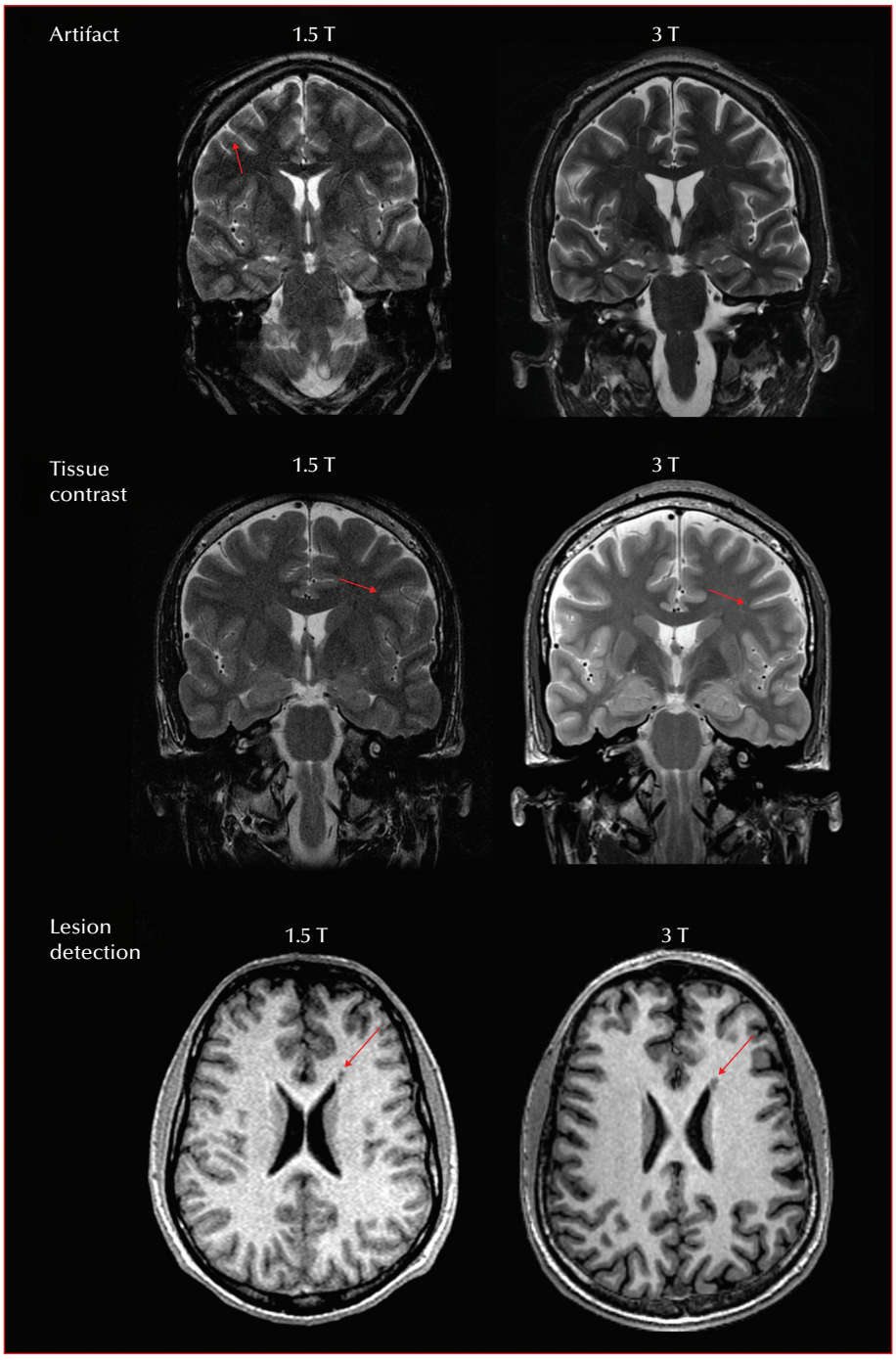
▼ **Table 2.** Summary of patient demographics, clinical features, investigations and final presumed seizure localization in the six patients in whom differences were observed between the 1.5 and 3T scans.

ID	Seizure onset age (yrs)/ Sex	Time from seizure onset to 1.5T scan (yrs)	Interval between 1.5 and 3T scans (yrs)	Time from seizure onset to 3T scan (yrs)	Seizure frequency	Seizure types	Interictal (VEM or EEG)	Ictal onset (VEM)	Ictal SPECT	Presumed SOZ	MRI findings	Scan where lesion seen	Comment	MR uniquely contributory?
1	45/M	1	0.5	1	q < 1yr	FA, FBTC	Normal	N/A	N/A	Temporal, lateralisation uncertain	Left hippocampal enlargement and T2 hyperintensity	3 T	Lesion seen at 3T possibly due to smaller interslice gaps	Yes
2	23/M	10	0.3	10	q 1 mo	FIA, FBTC	Left temporal IEDs	Left temporal	N/A	Left temporal	Left amygdala slighted enlarged with T2/FLAIR hyperintensity	3 T	Lesion seen at 3T possibly due to smaller interslice gaps	No
3	22/F	1	5.4	6	q 1 wk	FA, FIA, FBTC	Bilateral temporal IEDs	Bilateral temporal	N/A	Bilateral temporal	Left amygdala slighted enlarged with T2/FLAIR hyperintensity	3 T	Lesion seen at 3T possibly due to smaller interslice gaps	No
4	22/M	18	2.2	20	q 2wk	FIA, FBTC	Left anterior	Left hemispheric,		Multifocal epilepsy	Right amygdala	3 T	None.	No

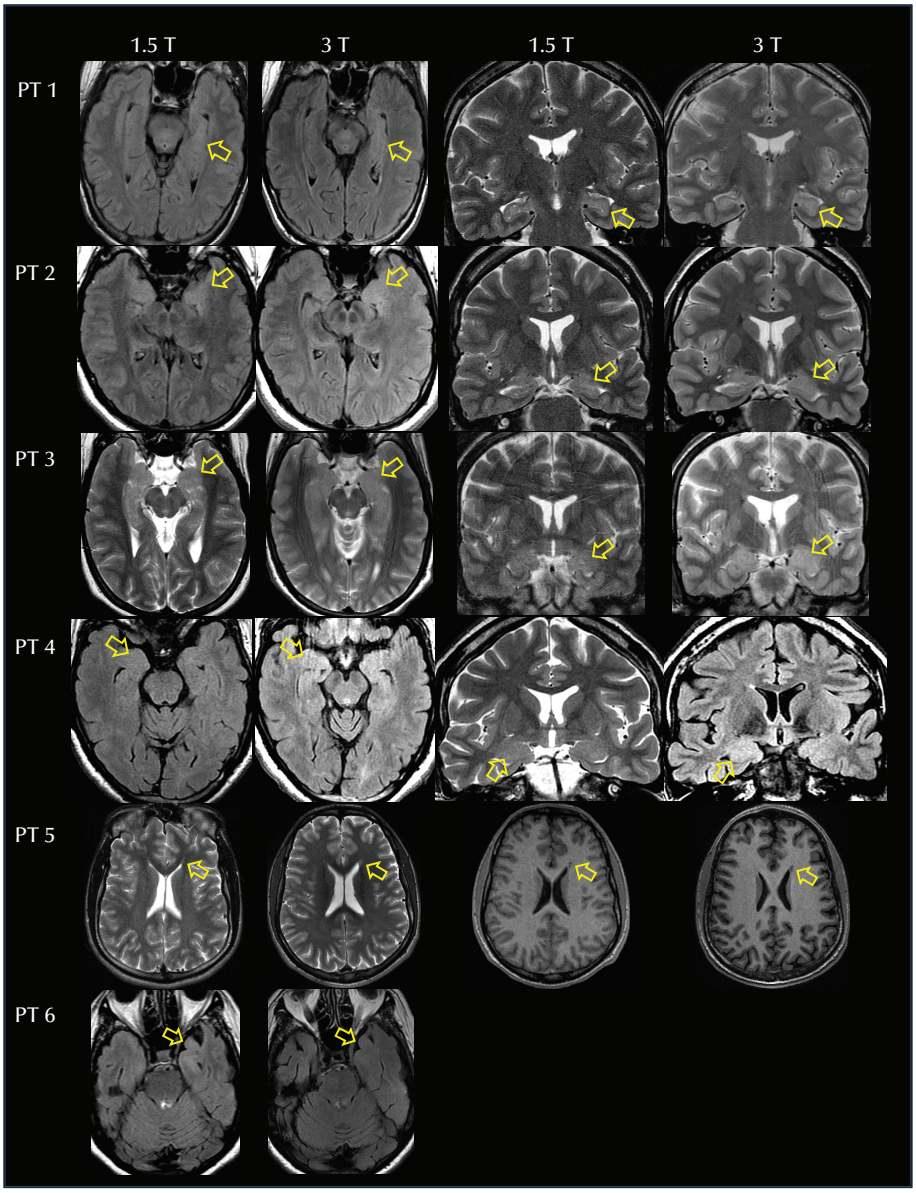
▼ **Table 2.** Summary of patient demographics, clinical features, investigations and final presumed seizure localization in the six patients in whom differences were observed between the 1.5 and 3T scans (*continued*).

ID	Seizure onset age (yrs)/ Sex	Time from seizure onset to 1.5T scan (yrs)	Interval between 1.5 and 3T scans (yrs)	Time from seizure onset to 3T scan (yrs)	Seizure frequency	Seizure types	Interictal (VEM or EEG)	Ictal onset (VEM)	Ictal SPECT	Presumed SOZ	MRI findings	Scan where lesion seen	Comment	MR uniquely contributory?
							& posterior temporal IEDs	right mid temporal	Right mid-temporal		slightly increased with T2/FLAIR hyperintensity			
5	26/M	1	4.5	5	q 6mo	FBTC	Left temporal IEDs	N/A	N/A	Left temporal	Heterotopic nodule adjacent to frontal horn of left lateral ventricle	3 T	Lesion seen at 1.5T but less clearly, due to smaller interslice gaps	No
6	55/F	5	3.1	8	q 6mo	FIA	Left temporal IEDs	N/A	N/A	Left temporal	Mild FLAIR hyperintensity in left anteromedial temporal lobe	1.5 T	None	No

FA: focal aware; FBTC: focal to bilateral tonic-clonic; FIA: focal impaired awareness; IEDs: interictal discharges; IS: ictal subtraction; mo: month; SOZ: seizure onset zone; VEM: video-EEG monitoring; wk: week; yr: year.



■ **Figure 1.** Qualitative differences between 1.5T and 3T scans. Upper row: qualitative improvement in artifact; red arrow shows the presence of motion artifact at 1.5T. Middle row: improved tissue contrast at 3T, as shown by the red arrows denoting a similar region between scans. Lower row: differences in lesion detection; the red arrows point to a periventricular nodular heterotopia that is more apparent at 3T.



■ **Figure 2.** Patients in whom changes were seen at one field strength but not the other. Patients 1-4 showed subtle T2 hyperintensity and/or bulk in the amygdala or hippocampus at 3T. Patient 5 had a heterotopic nodule that was identified at 3T. This was not initially seen at 1.5T, but on re-review of both scans, this was visible at 1.5T, but not as clearly. Patient 6 had T2 hyperintensity in the anteromedial temporal neocortex that was more visible at 1.5T, compared to 3T.

potential seizure onset zone that was not otherwise available in only one patient (Patient 1). This patient did not undergo video-EEG monitoring as this was not clinically indicated since he was seizure-free on antiseizure medications. For the other patients, the very subtle changes did not provide any unique localizing information that was not already available on EEG or video-EEG monitoring. Specifically, the location of the MRI changes was concordant with location of the presumed seizure onset zone in two patients with a single presumed seizure onset zone (Patients 2 and 6), and one of these patients had a possible abnormality at 1.5T only. The MRI changes were concordant with one presumed seizure onset zone in two patients with more than one possible seizure onset zone (Patients 3 and 4). The heterotopic nodule that was seen in both scans, but better visualized at 3T, was not considered

▼ **Table 3.** Summary of contrast scores, artifact scores, and number of lesions detected at 1.5T and 3T.

Scoring metric	1.5 T (Median, IQR)	3 T (Median, IQR)
Contrast score	3, 0.875	4, 0.5
Artifact score	3.25, 0.5	3.5, 1.0
Lesions detected	48	52

clinically relevant as this was not in the lobe of interest (Patient 5).

For all scans, both tissue contrast and artifact scores were significantly improved at 3T as determined by a Wilcoxon matched-pairs signed rank test ($p<0.0001$ and $p<0.0002$, respectively) (*table 3*, *figure 1*). In addition, more lesions overall were reported at 3T (52) compared to 1.5T (48) (*table 3*). *table 4* summarizes the potentially epileptogenic lesions seen at 3T. These included hippocampal sclerosis (20), malformation of cortical development (12), trauma (3), neoplasm (7), unilateral amygdala enlargement +/- subtle T2 hyperintensity (6) and other/non-specific lesions (4).

The location of interictal EEG abnormalities were compared to the location of the MRI lesions (*table 5*). In 55 cases with temporal lobe EEG abnormalities, the locations of the MRI abnormalities were concordant with EEG in 20 cases at both field strengths, in five cases with 1.5T only, and in seven cases with 3T only. In the 14 cases with frontal lobe EEG abnormalities, MRI findings were concordant with EEG in four cases at both field strengths, in no cases with 1.5T only, and in one case with 3T only. MRI did not identify epileptogenic lesions in the two cases with occipital interictal EEG abnormalities. In the 14 cases with interictal abnormalities in more than one lobe, MRI findings were concordant with EEG in at least one lobe in three cases at both field strengths, in one case with 1.5T only, and in one case with 3T only.

In the general linear model, various factors that could affect lesion detection were assessed. Neither qualitative tissue contrast, artifact scores, or field strength influenced the ability to detect a lesion (*table 6*). The only significant fixed effect was the presence of a focal EEG abnormality, regardless of field strength (*table 6*) (odds ratio: 13.21; $p<0.001$).

There was agreement of both reviewers for all 200 scans except five. The disagreements were all related to differences in the interpretation of very subtle, questionable changes. Specifically, one reviewer (not always the same reviewer) identified the following subtle changes: increased amygdalar T2 signal at 3T, loss of hippocampal internal architecture at 3T, increased amygdalar T2 signal at 1.5T, increased hippocampal T2 signal at 1.5T, and increased amygdalar bulk at 1.5T. The other reviewer felt that these scans were within normal limits. Based on review of these cases by a third neuroimaging expert (PF) and subsequent consensus, these scans were considered to be within normal limits.

Discussion

The success of surgical resection is contingent on the accurate localization of the seizure generating tissue [17]. Indeed, identification of a visible lesion on structural MRI significantly increases the chance of post-surgical seizure freedom [17, 18]. Thus, it is common to order a higher field (3T) scan if a 1.5T scan is unremarkable. However, this study demonstrates that a simple increase in field strength is not necessarily helpful. This is an important finding for patients being assessed for epilepsy surgery in resource-poor locations with limited access to MRI scanners.

Group statistical analysis

On initial inspection, the improved contrast and artifact scores as well as increased lesion detection, suggests that 3T MRI imaging may be superior to 1.5T imaging. However, this difference was not significant when the general linear model was derived. Indeed, only the presence of a focal EEG abnormality was predictive of detecting an MRI lesion at 1.5 or 3T, which was not unexpected as this would focus the MRI scan review. The observed improvement in contrast at 3T is expected [19]. However, there was no corresponding significant increase in lesion detection when considering all patients. This may be due to a ceiling effect of tissue contrast.

The apparent discrepancy between detecting more lesions at 3T and lack of significance of field strength in the linear model can be explained by the fact that although 3T scans contained more identifiable lesions, these extra lesions were in the same areas where lesions were seen on both 1.5T and 3T scans. Furthermore, there were a number of cases where a lesion was identified only at 1.5T but not 3T, and vice versa, suggesting that field strength does not play a significant role in our patient group.

The observed improvement in artifact with 3T was unexpected and contrasts previous studies [20, 21]. One possible explanation is that our study evaluated artifact qualitatively using a qualitative 4-point Likert scale. Another source of artifact in our study was motion artifact, which was more prevalent at 1.5T. Despite the presence of more motion artifact at 1.5T and a better artifact score at 3T, there was still no significant difference in lesion detection between the

▼ **Table 4.** Potentially epileptogenic lesions seen on 3T scans.

Diagnosis	Number (%)		
	All subjects (*n* = 100)	1.5T scan first (*n* = 52)	3T scan first (*n* = 12)
Normal	48 (48%)	39 (75%)	9 (17%)
Hippocampal sclerosis	20 (20%)	17 (33%)	3 (6%)
Unilateral	17	14	3
Unilateral with dual pathology	1	1	0
Bilateral	2	2	0
Malformations of cortical development	12 (12%)	12 (23%)	0 (0%)
Focal cortical dysplasia	9	9	0
Heterotopia	2	2	0
Polymicrogyria	1	1	0
Neoplasm	7 (7%)	5 (10%)	2 (4%)
Dysembryoplastic neuroepithelial tumour	1	0	1
Ganglioglioma	1	1	0
Meningioma	1	1	0
Glioma	1	0	1
Unspecified	3	3	0
Unilateral amygdalar enlargement +/- T2-FLAIR hyperintensity	6 (6%)	5 (10%)	1(2%)
Trauma	3 (3%)	2 (4%)	1 (2%)
Trauma - encephalomalacia (bilateral)	2	2	0
Trauma – remote microhaemorrhages (bilateral)	1	1	0
Other	4 (4%)	3 (6%)	1 (2%)
Cortical atrophy	2	2	0
Meningoencephalocele	1	1	0
Superficial siderosis and remote intracerebral haemorrhage	1	0	1

▼ **Table 5.** Concordance of EEG findings and MR lesion location. The anatomical regions where EEG abnormalities were seen are separated by lobe, and multifocal cases were placed in a separate group. Note that concordance relates to the location of an MRI abnormality (if present) at 1.5T or 3T relative to the location of the EEG abnormality.

Location of EEG abnormality	Both 1.5 and 3T concordant	Only 1.5T concordant	Only 3T concordant	Neither 1.5T nor 3T concordant
Temporal lobe	20	5	7	23
Frontal lobe	4	0	1	6
Occipital lobe	0	0	0	2
Multifocal	3	1	1	9

▼ **Table 6.** Fixed effects in the general linear model of lesion conspicuity.

Fixed effects	Odds ratio	95 % Confidence interval	*p* value
Higher-field strength	1.04	0.80-1.34	0.787
EEG localization	13.21	8.55-20.42	**<0.001**
Contrast score	0.95	0.74-1.22	0.698
Artifact score	0.98	0.82-1.18	0.842

two field strengths. This implies that the artifacts reported were either not significant or not present in critical regions that would impair lesion detection.

Clinical relevance

One important consideration is statistical significance versus clinical significance. We observed no statistical difference between lesion detection at 1.5T versus 3T. However, there were six cases out of 100 (6%) in which a difference was seen. In five cases, an abnormality was seen at 3T but not 1.5T, and in one case, the reverse was true. However, four of these five cases involved very subtle and questionable swelling and T2 hyperintensity of the amygdala or hippocampus, which in most cases, could not be identified as being definitively abnormal. Indeed, these changes may have been missed if the images were not reviewed by an experienced neuroradiologist who was also provided with relevant clinical information. Furthermore, in four out of five cases, there were subtle differences in image acquisition parameters between 1.5T and 3T (smaller interslice gaps in the axial FSE and FLAIR, 7.5 vs 5.0 mm), which may impact lesion visibility. Lastly, our centre has a research interest in amygdalar swelling which may have increased the detection rate of such abnormalities. Thus, while there was a 5% chance (five patients) of seeing a lesion at 3T but not 1.5T, subtle differences in image acquisition parameters may have resulted in greater lesion visibility at 3T in four cases. Of these five cases, 3T MRI produced unique localizing information about a potential seizure onset zone that was not otherwise available for only one patient (Patient 1). It is important to note, however, that providing imaging evidence that is concordant with a suspected seizure onset zone based on other data (*e.g.*, EEG, seizure semiology, PET, SPECT) is also important information to be considered in epilepsy presurgical investigations.

Practical considerations

There are several practical considerations related to our findings. First, as we have shown, clinical information and localizing EEG data are important for the radiologist to consider when interpreting and reporting epilepsy MRI examinations. However, no other study has examined the effect of providing clinical information on interpretation of MRI scans in epilepsy. One study on stroke imaging showed a trend towards clinical information affecting clinical decision making [22]. Previous studies involving other imaging modalities such as radiographs [23] and CT [24] also stressed the importance of clinical information in facilitating the correct radiographic diagnosis. Indeed, inaccurate or an incomplete history account for about 2% of radiographic diagnostic errors [25]. There are arguments that clinical information would bias the reader [26], but a systematic review did not support this [27]. The neuroradiologists in our study had all relevant clinical information available to them to best simulate a realistic clinical scenario, similar to how a multidisciplinary epilepsy team would approach such cases. This allowed the neuroradiologists to focus their examination of the scans, which in turn, may have been a contributing factor towards the equalization of lesion detection between 1.5T and 3T scans. This showcases how ensuring that the radiologist has sufficient background clinical information, especially EEG localization, as well as effective multi-disciplinary collaboration, can improve diagnostic yield and increase lesion detection regardless of field strength. Second, the expertise and experience of the image reader is also critical and increases diagnostic yield [8, 28] which, in turn could lessen the beneficial impact of 3T compared to 1.5T. This expertise arises from specialized training, increased workload, repeated exposure to images and constant clinical and pathological feedback as part of working in a multidisciplinary team.

Thirdly, as shown in previous studies and as discussed earlier, technical differences (*e.g.*, slice thickness, interslice gaps) could potentially impact lesion detection between scans [8-10]. Given this, diagnostic imaging centres should now use the HARNESS protocol, as recommended by the Neuroimaging Task Force of the International League Against Epilepsy in 2019 [11]. Use of the HARNESS protocol optimizes and standardizes epilepsy neuroimaging across different centres. Specifically, the HARNESS protocol includes three important acquisitions: i) high-resolution 3D T1-

weighted acquisition with isotropic millimetric voxel resolution (1×1 x 1 mm^3 with no interslice gaps), ii) high-resolution 3D FLAIR acquisition with isotropic millimetric voxel resolution (1×1 x 1 mm^3 with no interslice gaps), and iii) high in-plane resolution 2D coronal T2-weighted MRI; acquired perpendicular to the long axis of the hippocampus using submillimetric voxel resolution ($0.4 \times 0.4 \times 2$ mm) with no interslice gap. It is possible that using the HARNESS protocol at 3T could improve lesion detection over 1.5T scans acquired using older seizure protocols. However, our study cannot answer this question as our MR scans were acquired before the development and publication of the HARNESS protocol.

Comparison to previous studies

Our study contrasts previous studies suggesting that 3T scans may offer clinical benefit over 1.5T scans. However, our study showed that lesion detection is strongly correlated with the presence of focal EEG abnormalities and thus, the MRI scans did not provide unique localizing information. On the other hand, our findings are in agreement with previous studies that demonstrate increased lesion detection at 3T [29].

In summary, previous studies comparing 1.5 to 3T MRI scans had limitations. Most had small sample sizes (<40 subjects) and were therefore underpowered to use a linear model, as we have done [12, 14, 15, 30]. Some studies had no direct review of 1.5T scans, but instead relied on the clinical MRI reports [14, 30]. This would bias the results towards lesion detection at 3T. Some studies also had no availability of relevant clinical information to focus the review of MRI scans [13, 14]. The only previous study of a large patient group (n=804) spanned over 16 years and used 3T scanners whose hardware significantly improved over the course of the study [13]. This would again bias the results towards improved lesions because of better hardware at 3T and because lesions can certainly evolve over the 16-year time span to become more apparent on repeat imaging.

Our study also differed from most previous studies in that we included all patients with epilepsy rather than only those with drug-resistant epilepsy [12, 14, 15]. A 3T MRI scan may be ordered for patients with drug-resistant epilepsy for better delineation of margins of an identified lesion rather than just lesion detection. In our study and another study [13] which included all patients with epilepsy, the most common lesion with a single aetiology was hippocampal sclerosis. In contrast, in studies where patients with medication-resistant epilepsy were assessed, focal cortical dysplasia was more common than hippocampal sclerosis [12, 14, 15]. In our study, the lesions that showed differences between the scans were subtle (*table 2*).

Overall, previous studies suggest that there may be some limited benefit to repeating a seizure protocol scan at 3T in patients undergoing epilepsy presurgical investigations who have non-lesional 1.5T scans. However, in a less selective group of patients, such as those in the present study, imaging at 3T does not yield a similar benefit over 1.5T scanning.

Indications for repeat high-field strength imaging

Despite our reported results, we believe that there is still clinical value to repeat imaging at a higher field strength. Specifically, repeat imaging may be warranted if a patient's clinical condition changes significantly or if a long period of time passes between MRI examinations (*e.g.*, five years). As epilepsy can be a progressive disease, structural changes (*e.g.*, atrophy and gliosis) over time may advance to a point where a repeat imaging may identify an abnormality. For instance, even patients with epilepsy who are in remission have progressive grey matter atrophy that is detectable and quantifiable using MRI [31].

In addition, for non-lesional MRI scans, a potentially useful approach might be to perform follow-up MRI scans at higher-field strength and include different sequences that were not included in the original MRI study (*e.g.*, proton density, magnetic resonance spectroscopy, T2 relaxometry, susceptibility-weighted imaging, *etc.*). This may enhance the detection of subtle lesions such as focal cortical dysplasia, vascular malformations, tumours, and trauma. Other novel sequences, such as arterial spin-labelling MRI, may also be considered [32, 33].

Limitations

One potential limitation of our study is the time interval between scans, during which some lesions (*e.g.*, tumours) could evolve or other events (*e.g.*, head trauma, stroke, repeated seizures, *etc.*) can occur. Another potential limitation is some difference in acquisition parameters between scans that would favour lesion detection at 3T. However, despite these potential limitations, we observed no significant difference in lesion detection between 1.5 and 3T scans. Another possible limitation relates to the possibility that being provided all relevant clinical information may have negatively impacted lesion detection in this study. For example, it is possible that incidental, or less likely potentially relevant, lesions outside the seizure onset zone could be missed. However, neuroradiologists are trained to systematically review all areas of an MRI scan and not just a particular region of interest, making this possibility less likely. Lastly, it is possible that a reviewer may recall a case when reviewing it for a second time (at a different

field strength). However, the scans were reviewed in a semi-random order and spread out through the series, thus eliminating this recall bias.

Conclusion

We have shown that repeating MRI scanning with similar sequences in patients with focal epilepsy at 3T does not significantly increase diagnostic yield above 1.5T in a centre with experienced neuroradiologists working with a multidisciplinary team who have been provided with all relevant clinical information. Epilepsy centres should therefore strive to ensure that the interpreting radiologist has access to clinical and diagnostic localizing information. This is a particularly important consideration in resource-poor locations with limited access to MRI scanners. Despite this, there still may be clinical value in repeat imaging at higher-field strengths if a patient's clinical condition changes significantly or if a long period of time passes between MRI examinations. Additionally, repeat scanning at higher-field strengths with specialized sequences not used in the previous MRI scan may be of value. ■

Key points

- Lesion detection was compared between 1.5T and 3T MRI scans acquired in the same patients with epilepsy.
- Both the qualitative tissue contrast and motion/technical artifacts were improved at 3T.
- However, this did not result in statistically significant improvement in lesion detection.
- Repeat MRI scanning at 3T using similar scan protocols does not significantly increase diagnostic yield over scanning at 1.5T.

Supplementary material.
Summary slides accompanying the manuscript are available at www.epilepticdisorders.com.

Disclosures.
The authors report no disclosures.

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TEST YOURSELF

(1) What is (are) the most important factor(s) when considering ordering or reviewing an MRI scan?

A. Use of the HARNESS protocol
B. Providing detailed clinical information to the interpreting radiologist
C. Always obtaining MRI scans at the highest-field strength possible
D. A and B
E. All of the above

(2) Brain tissue contrast is improved at 3T compared to 1.5T.

A. True
B. False

Note: Reading the manuscript provides an answer to all questions. Correct answers may be accessed on the website, www.epilepticdisorders.com.