

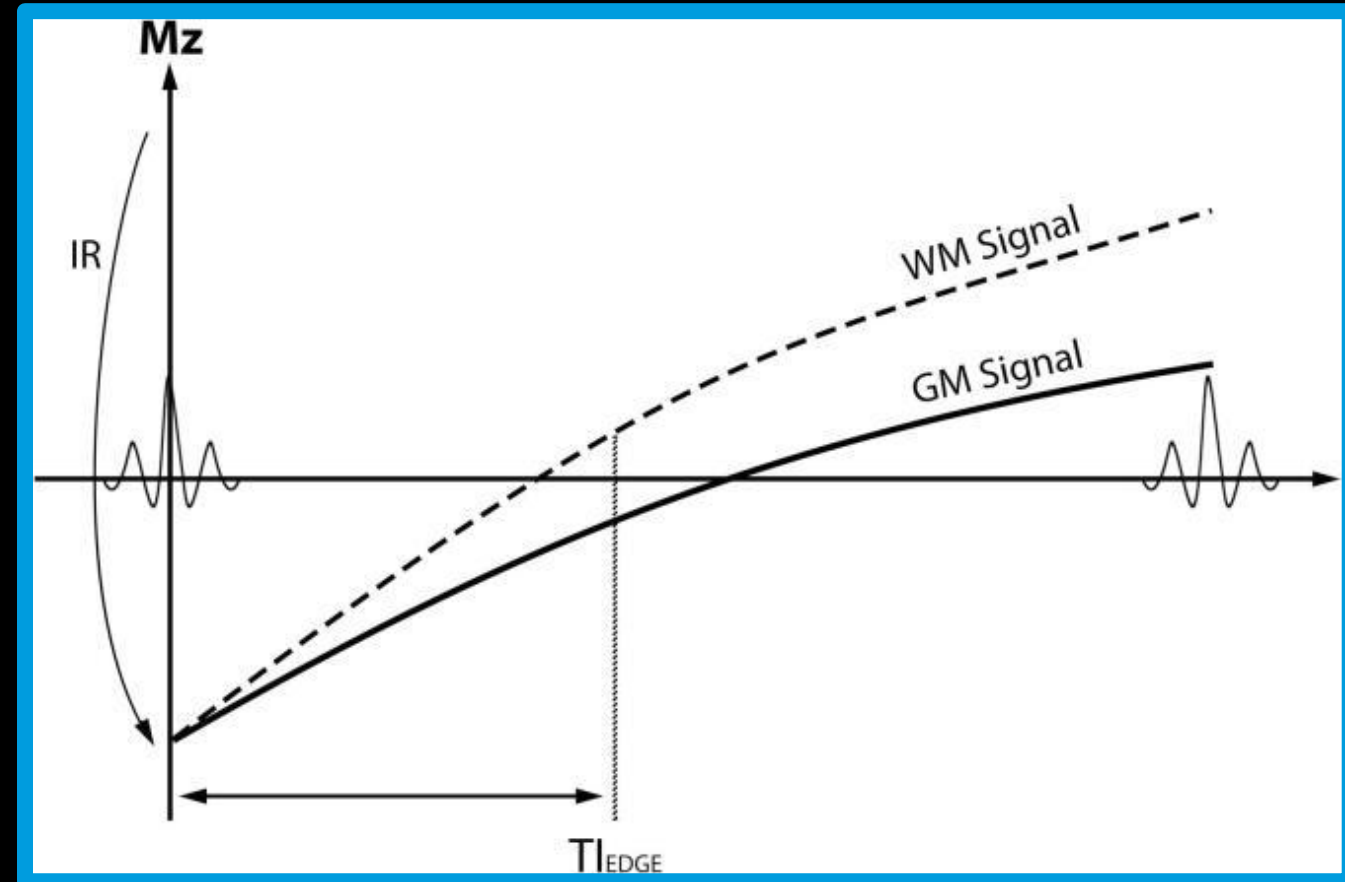
ZOOMING IN ON THE GREY–WHITE JUNCTION: TECHNICAL AND CLINICAL ADVANCES IN EDGE MRI

Manasi Arora MBBS , Vivek Gupta MD, Sanjana Kumar BS, Erik H.
Middlebrooks MD

Department of Radiology, Mayo Clinic, Jacksonville

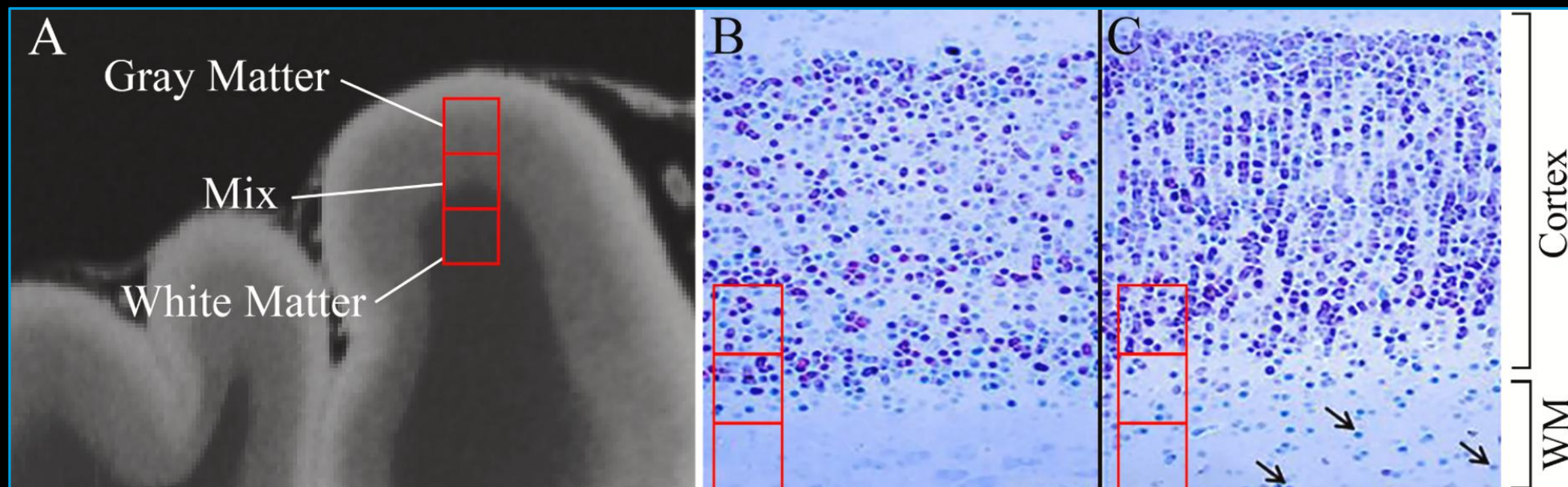
EDGE-ENHANCING GRADIENT-ECHO (EDGE) MRI

- EDGE MRI is optimized to detect subtle cortical boundary lesions, such as focal cortical dysplasia (FCD)
- **Principle:**
 - The inversion time (TI) in the 3D-EDGE sequence is optimized for GM and WM to have comparable signal intensity, but with opposite polarity of longitudinal magnetization
 - Signal void at the GM-WM boundary



GM: Gray matter; WM: White matter; IR: Inversion recovery;
 TI_{EDGE} : Inversion time of EDGE MRI

RAD-PATH CORRELATION OF EDGE MRI



- (A) Hypothetical MRI voxels (red squares) may contain entirely gray matter, white matter (WM), or a mixture.
- (B) Histologically, this cross-section area will show non-myelinated GM, myelinated WM and mixture of both myelinated and non-myelinated cells at the boundary. Given the optimized inversion times for normal gray matter and WM, those voxels with a mixture will show signal cancellation.
- (C) With an FCD, there is alteration in gray matter cell density along the WM boundary and abnormal ectopic neurons within the subcortical WM (arrows) producing a change in the normal inversion times and creating a “thickening” or distortion of the normal boundary line on 3D-EDGE.

MRI OF EPILEPTOGENIC LESIONS

Lesion	Histopathologic Abnormality	MRI Findings
FCD type Ia	Abnormal radial cortical lamination	Majority are MRI negative, but may show blurring of the gray/ white matter junction due to heterotopic U-fiber neurons
FCD type Ib	Abnormal tangential 6-layer cortical lamination	
FCD type Ic	Abnormal radial and tangential cortical lamination	
FCD type IIa	Dysmorphic neurons	Increased cortical thickness, blurring of the gray/white matter junction, abnormal gyral/sulcal pattern
FCD type IIb	Dysmorphic neurons + balloon cells	Findings of FCD Type IIa + Transmantle sign
FCD type IIIa	FCD I + hippocampal sclerosis	Not directly visible, but may show white matter hypoplasia + white matter blurring
Mild malformation of cortical development with oligodendroglial hyperplasia (MOGHE)	Increased number of oligodendroglial cells + ectopic neurons in white matter	Juxtacortical or subcortical bands of hypomyelination with/without white matter blurring

SYSTEMATIC APPROACH TO EDGE MRI

Scan the GW line

- Look for **asymmetry**, **thickening**, or **irregular edges** along the gray-white junction.

Trace radial clues

- Follow any **transmantle band** from cortex **toward the ventricle**.

Mirror-compare

- Check the **contralateral lobe/sulcus** for symmetry to avoid overcalling.

Cross-check sequences

- Verify the hotspot on **T1/T2/FLAIR** ($\pm$ **DIR**) for consistent findings.

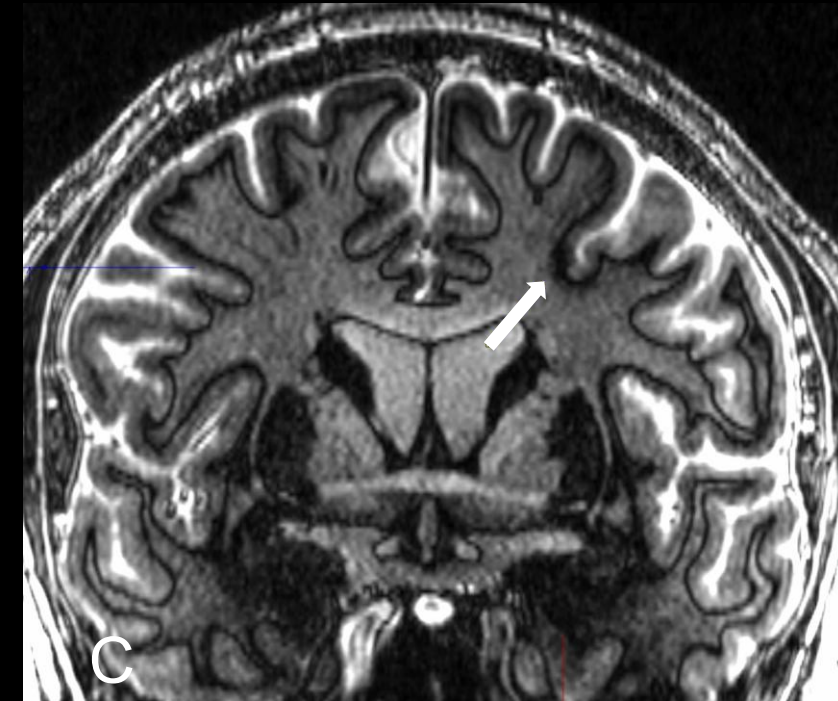
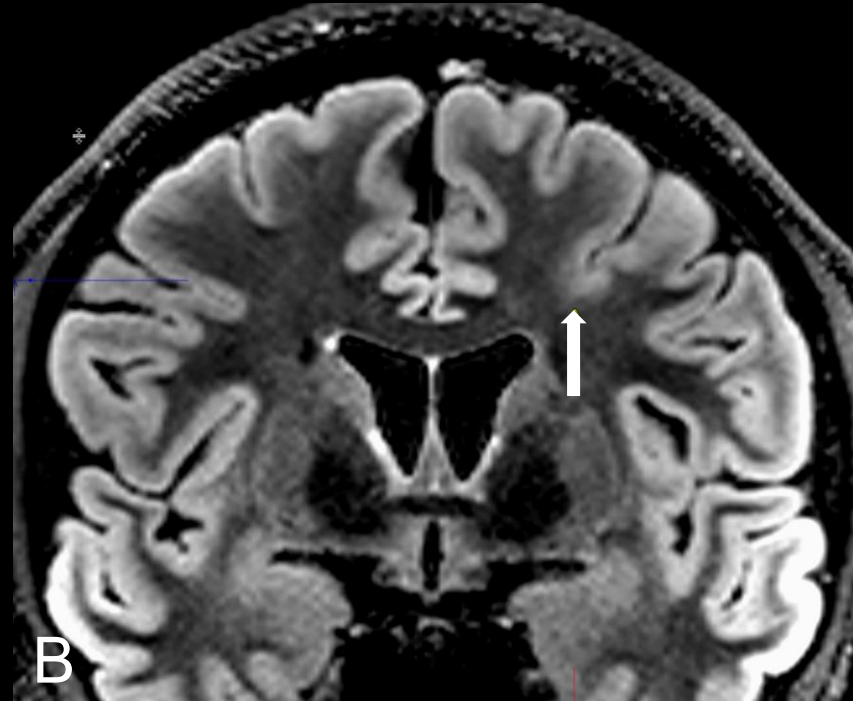
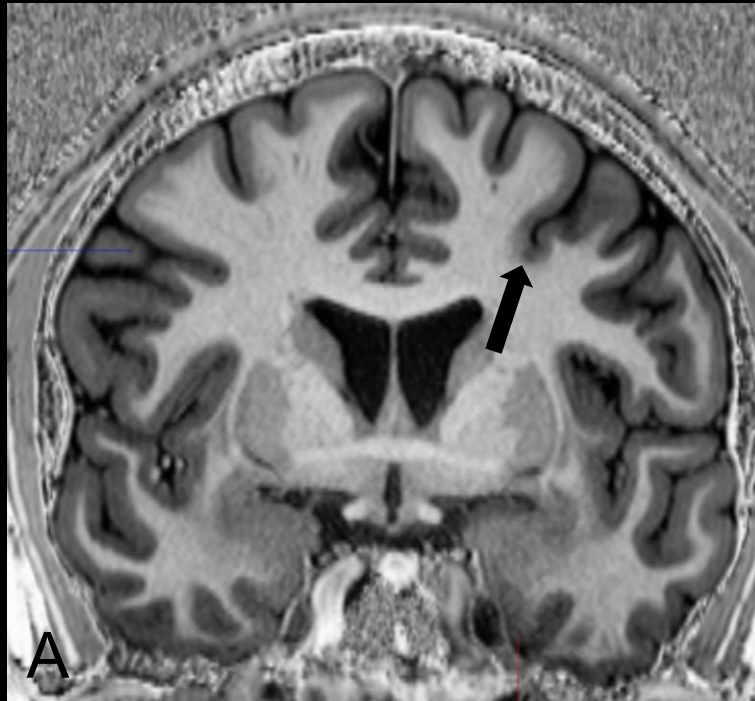
Correlate clinically

- Align with **EEG/semiology** ($\pm$ **PET**) before elevating to a target.

CASE EXAMPLES

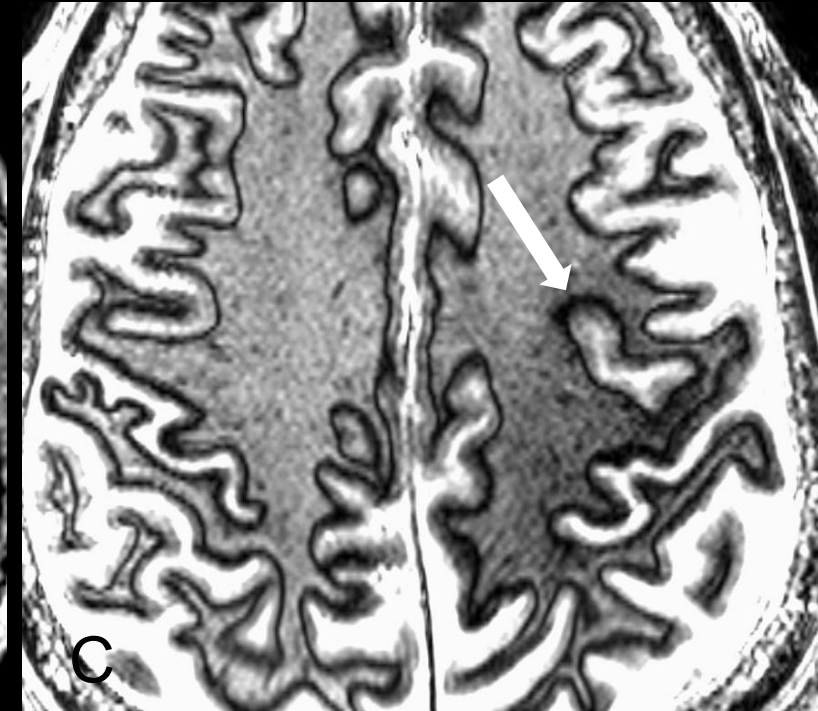
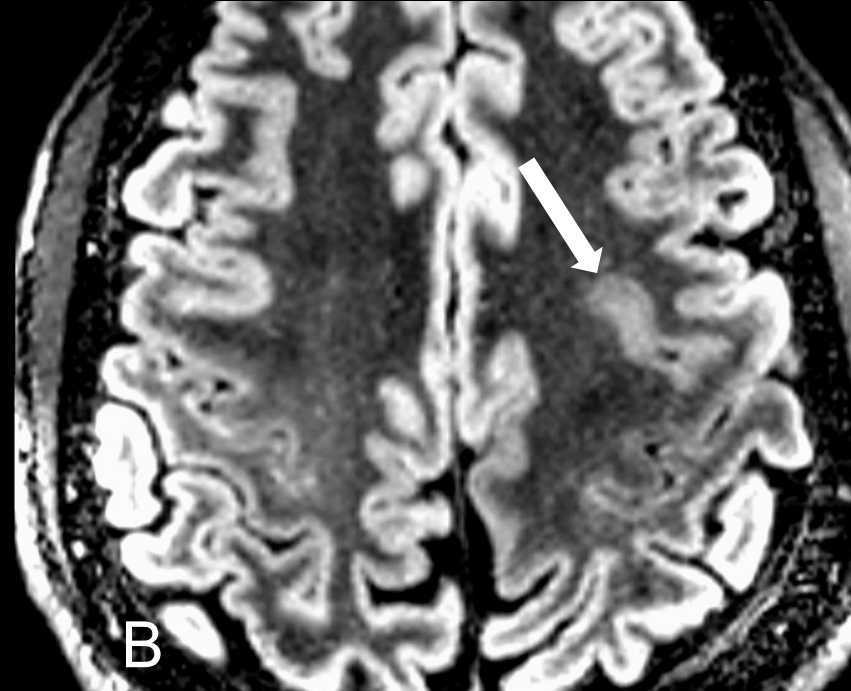
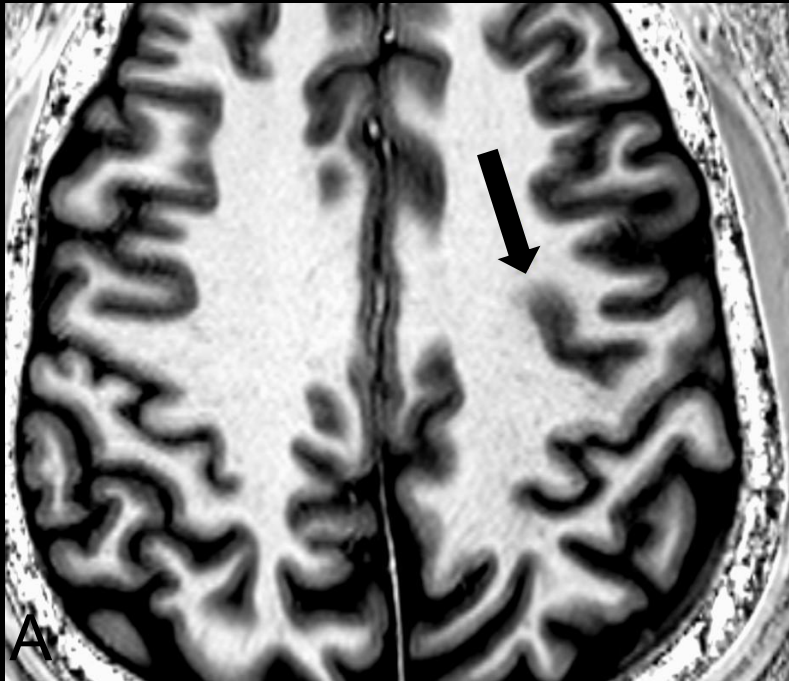


GW BOUNDARY THICKENING AND BLURRING



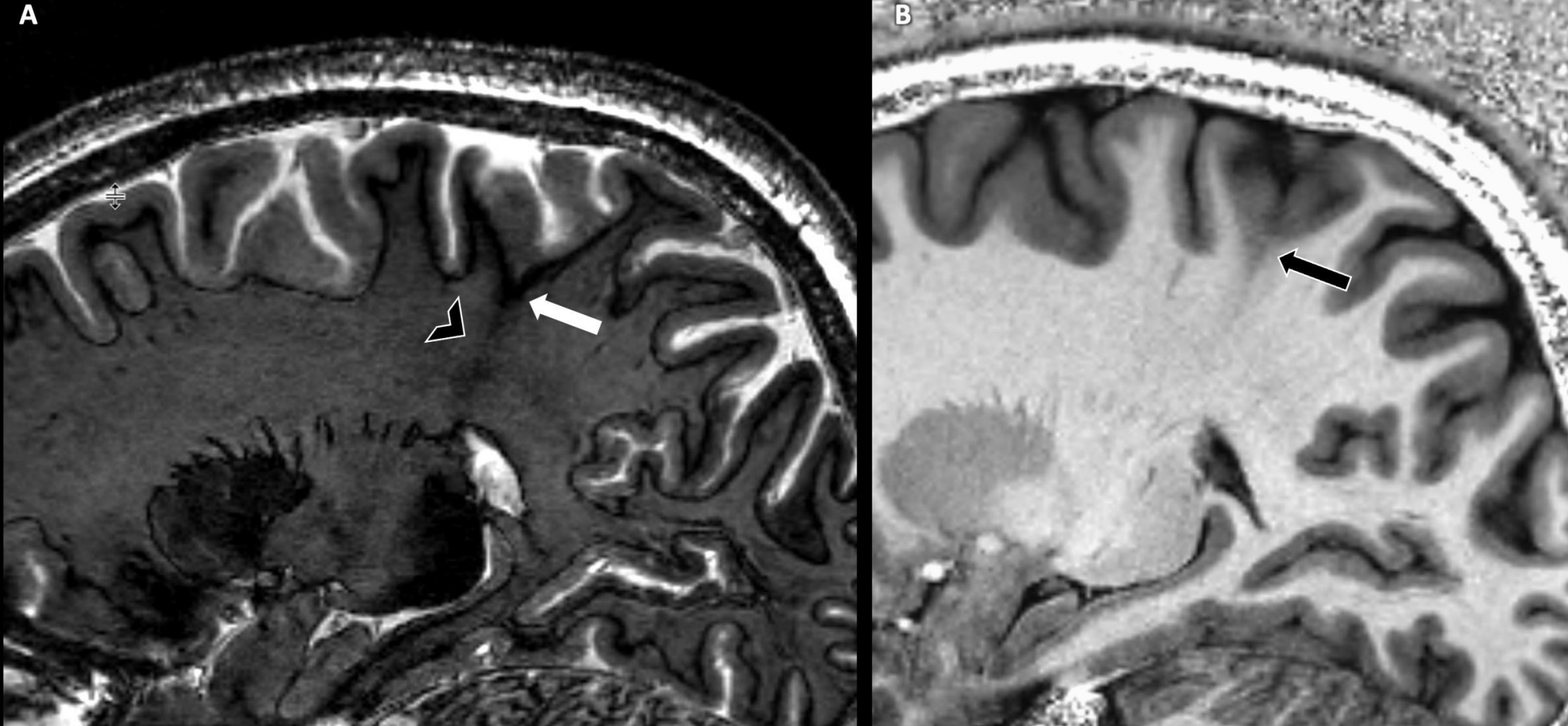
Epilepsy protocol 7T MRI of a 21y/M demonstrates a focal area of gray-white blurring and thickening of the gray-white boundary (arrow) on the EDGE sequence (C) within the posterior aspect of the left superior frontal sulcus. These findings are suspicious for small Type I or Type IIa focal cortical dysplasia, which can be seen as very subtle changes on MP2RAGE (A) and T2-FLAIR (B) sequences. This was later treated with laser interstitial thermal therapy (LITT), and the patient has remained seizure-free to date.

GW BOUNDARY THICKENING AND BLURRING



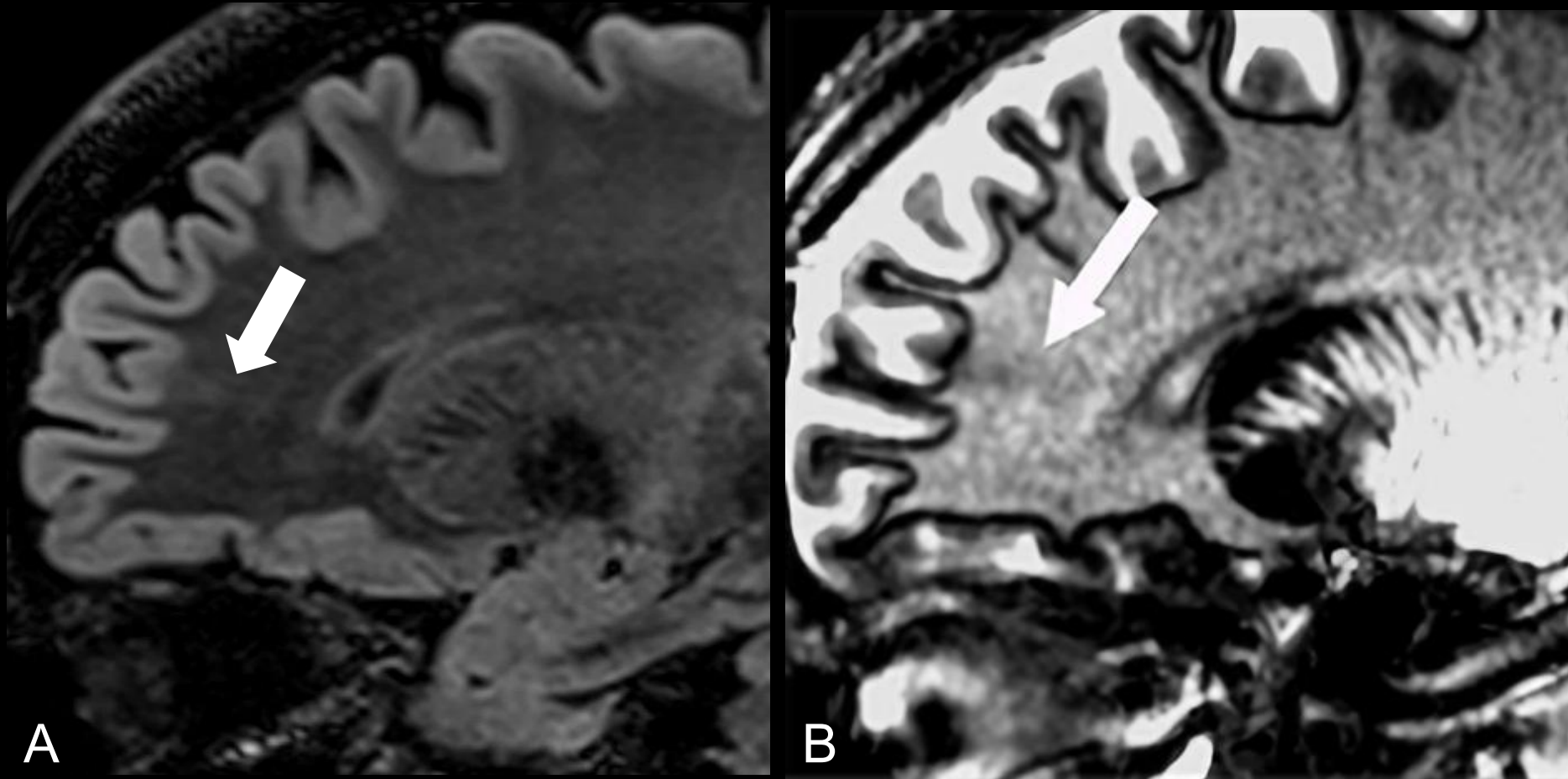
Another case example of a 19 y/M with drug resistant epilepsy underwent 7T MRI that showed area of focal thickening and blurring of the gray-white junction along the base of the left superior frontal sulcus near the expected region of the frontal eye field. This is best visualized on the EDGE MRI sequence (C), in contrast to the very subtle findings on MP2RAGE (A) and FLAIR (B) sequences. This is suspicious for FCD Type Ib or IIa.

TRANSMANTLE SIGN



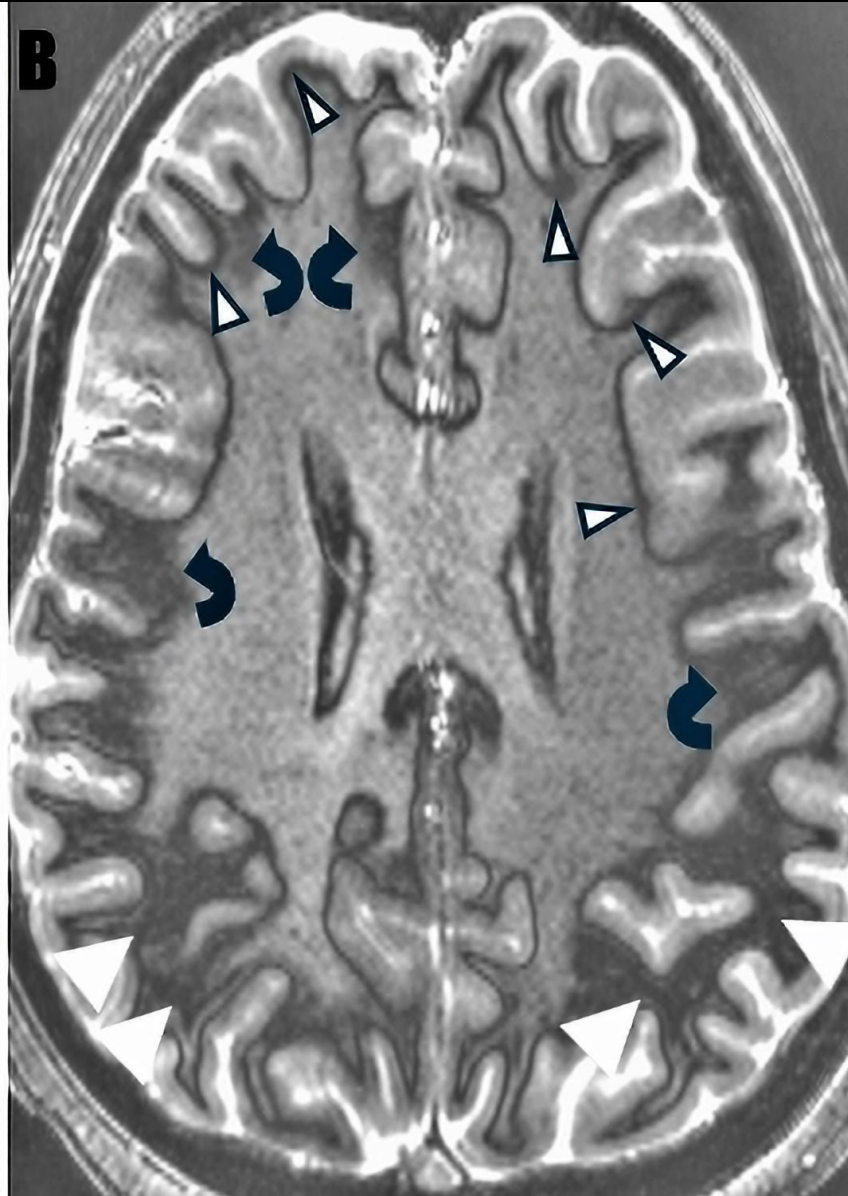
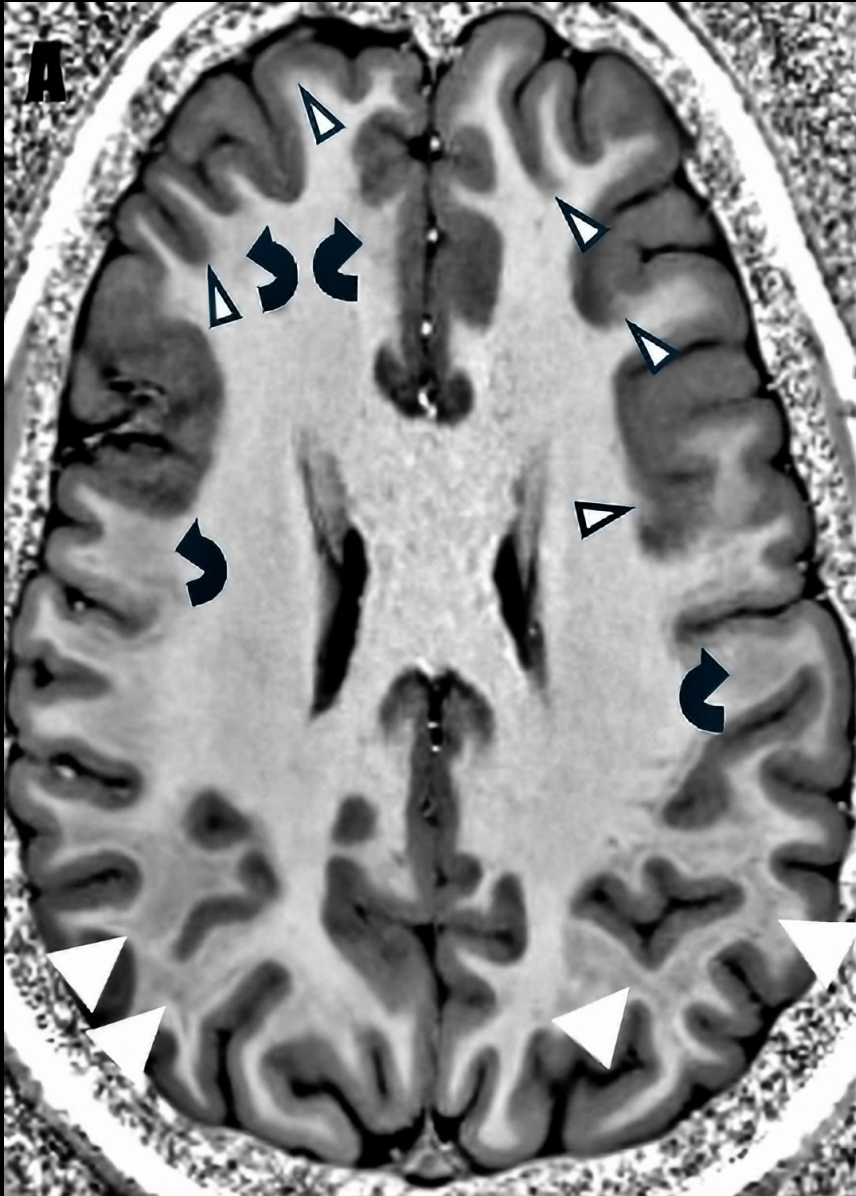
A case example of 16y/F with history of focal seizure since 3 years of age. (A) Sagittal 7T EDGE shows focal thickening of the GM-WM junction (arrow) at the base of the left postcentral sulcus with subtle band of subcortical white matter hypointensity extending towards the lateral ventricle (transmantle sign, arrowhead). (B) Sagittal 7T MP2RAGE T1-weighted uniform shows more subtle blurring of the GM-WM junction (arrow).

TRANSMANTLE SIGN



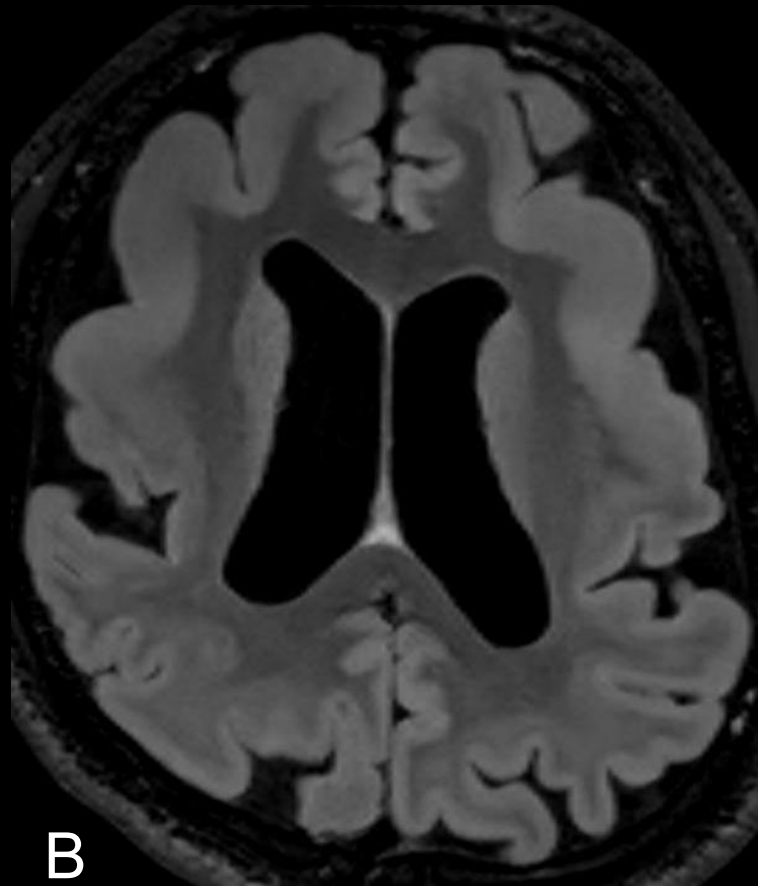
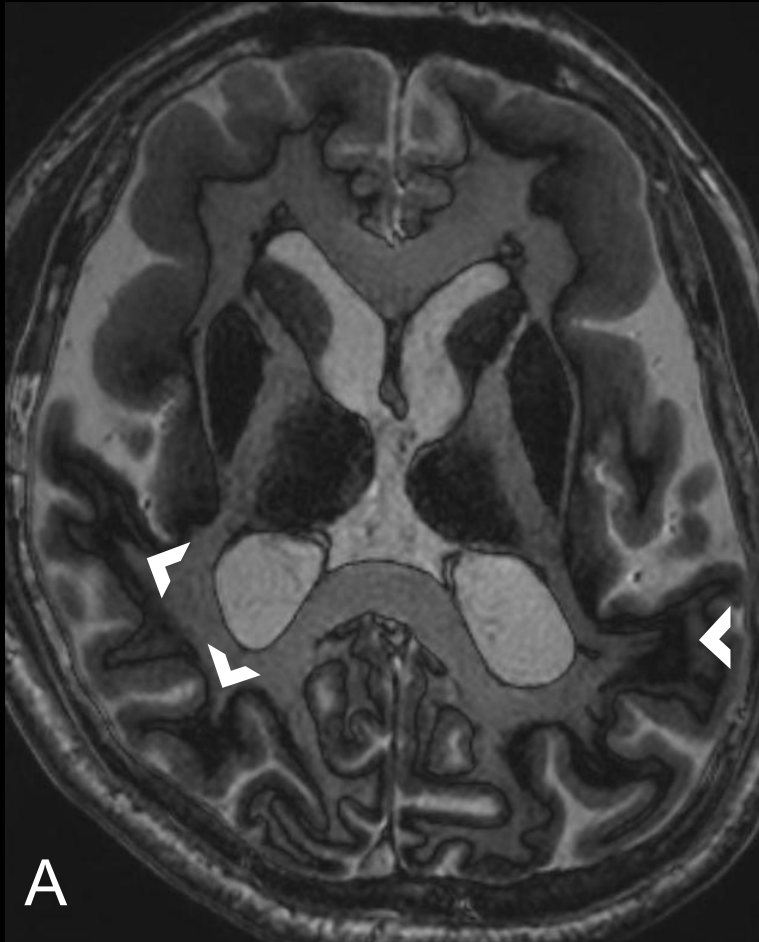
A companion case of a 29y/M underwent Epilepsy protocol 3T MRI that showed a linear hyperintense signal extending from the base of the left superior frontal sulcus towards the frontal horn of lateral ventricle on the sagittal FLAIR (A) that appears to be contiguous with the overlying cortex on EDGE sequence (B) and is suspicious for type IIb focal cortical dysplasia.

SUBCORTICAL BAND HETEROTOPIA



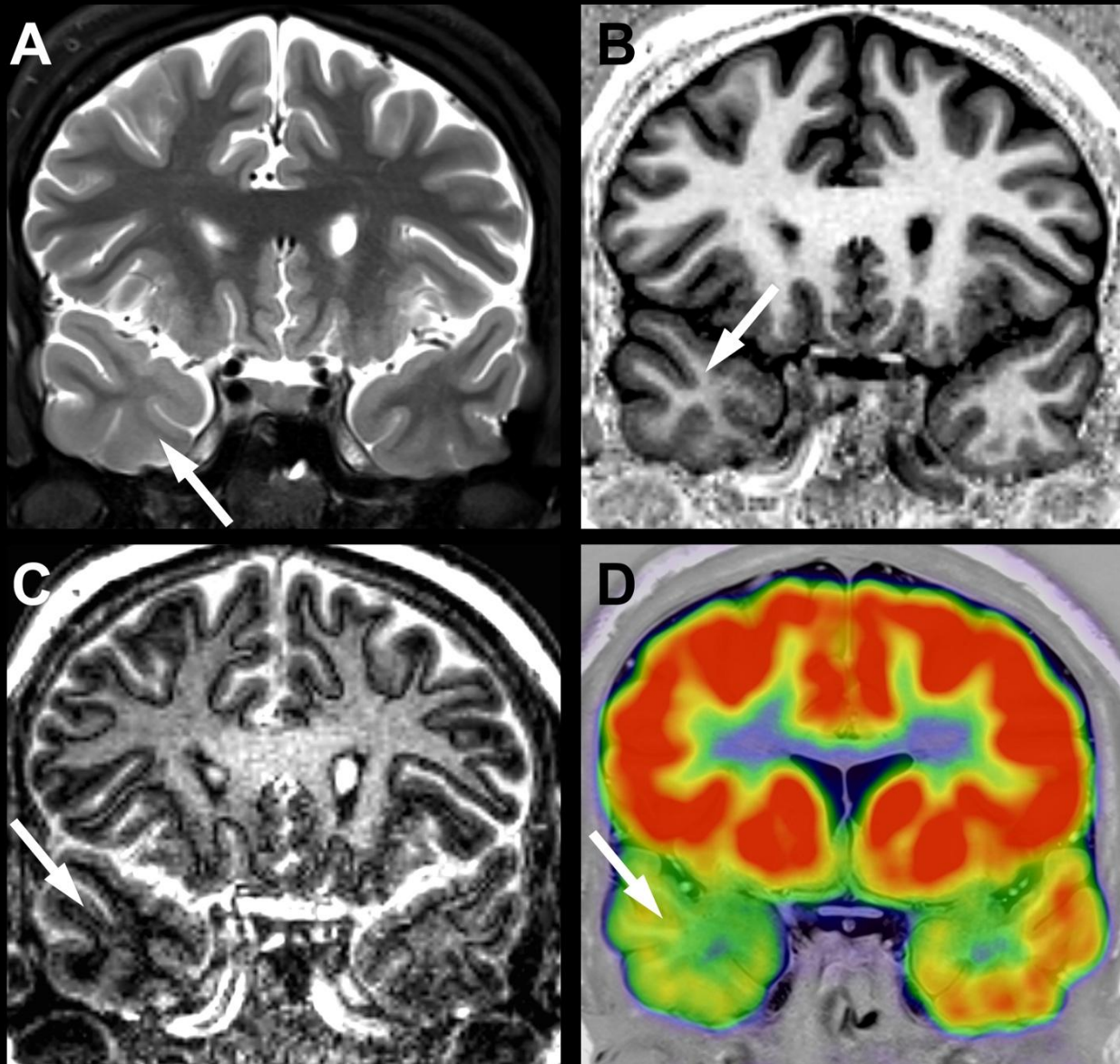
Axial MP2RAGE (A) and EDGE (B) sequences demonstrate subcortical band heterotopia (SBH) bands (arrowheads) on EDGE are surrounded by more diffuse abnormality of the immediate juxtacortical white matter which appears normal on MP2RAGE. The regions of hazy subcortical white matter on MP2RAGE (curved arrows) are distinctly more conspicuous on EDGE. Barely noticeable multifocal bottom of sulcus blurring of the GM-WM junction (arrowheads) suggestive of type 1b FCD is conspicuously revealed on EDGE as widening of the junctional linear stripe.

LISSENCEPHALY WITH SUBCORTICAL BAND HETEROTOPIA



Case example of a 23 y/M demonstrates mild diffuse cortical thickening and pronounced paucity of sulcation bilaterally in the frontal lobes with relatively more normal-appearing sulcation pattern, and presence of diffuse subcortical band heterotopia (arrowheads) in the parietal and temporal lobes on the EDGE MRI (A) versus subtle changes on FLAIR (B) and MP2RAGE MRI (C). The most normally formed cortex is present bilaterally in the occipital lobes which shows near normal sulcation and cortical formation, and absence of subcortical band heterotopia.

TEMPORAL POLE BLURRING



Case example of a 20y/M with a long-standing seizure disorder. T2-weighted (A) and SPACE inversion recovery (B) sequences reveal subtle blurring of the gray-white junction with slight increase in T2 signal in the subcortical white matter of the right temporal pole (arrow).

Coronal 3D-EDGE (C) shows unequivocal diffuse hypointensity of the subcortical white matter of the right temporal pole (arrow).

Coronal FDG-PET (D) reveals diffuse hypometabolism of the right temporal pole consistent with temporal pole blurring.

EDGE MRI- 3T vs 7Tvs DL Reconstruction

Standard 3T EDGE-MP2RAGE

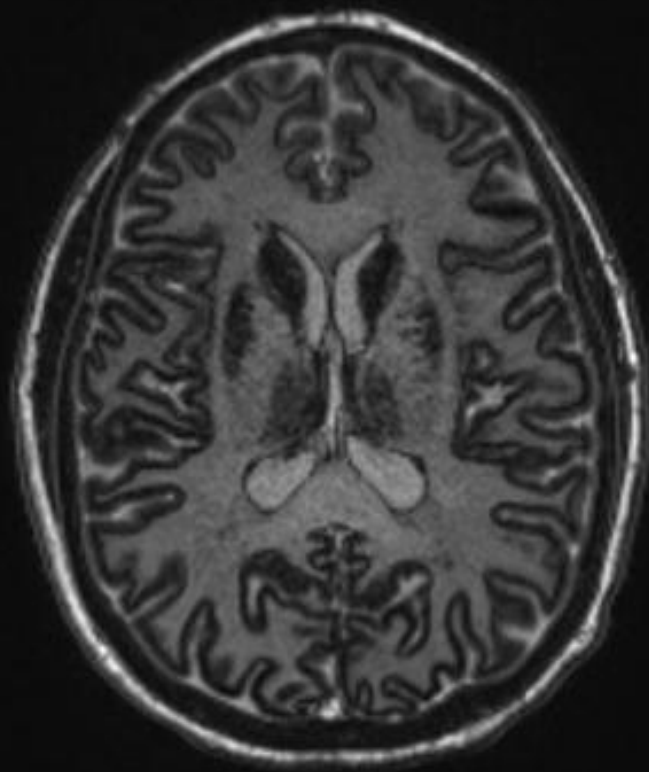
- High contrast at GM-WM junctional images
- Tissue signal nulling effect resulting in low signal-to-noise ratio (SNR)
- Aggressive acceleration techniques to shorten scan time further worsens SNR

7T EDGE- MP2RAGE

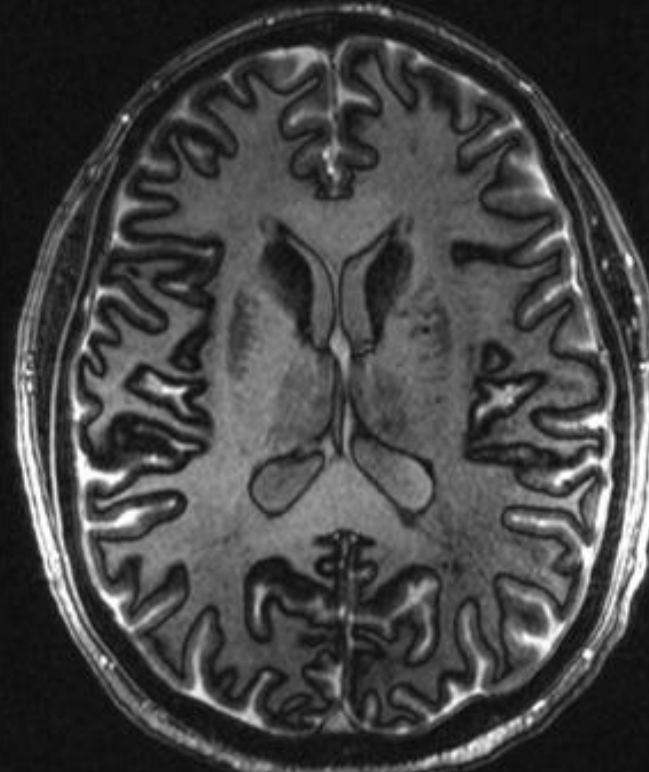
- Improved SNR due to higher field strength
- Contrast uniformity can vary due to B1+ transmit inhomogeneity
- Limited availability

3T DL EDGE- MP2RAGE

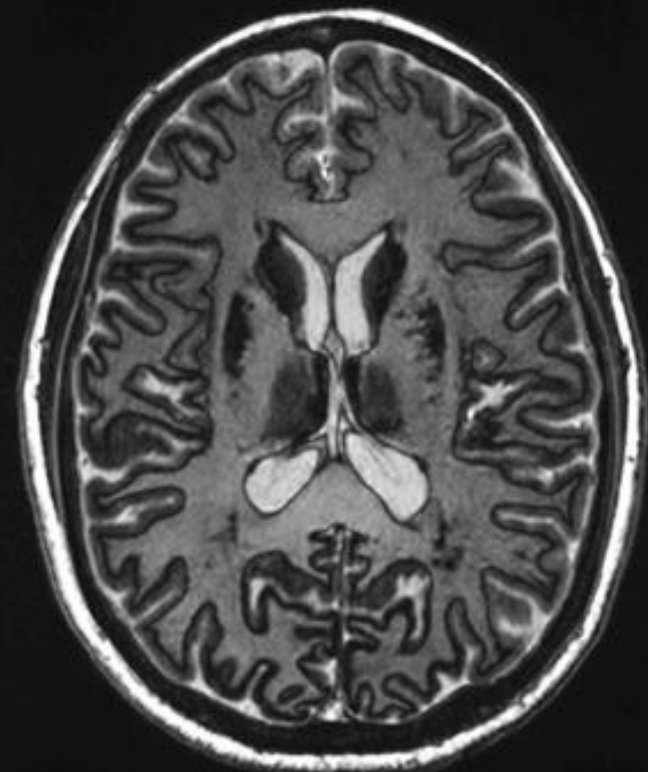
- Improved SNR
- Improved contrast uniformity by decreasing noise and no B1+ transmit inhomogeneity
- Widely available with shorter scan times



Standard 3T EDGE
1 x 1 x 1 mm
8:47



Standard 7T EDGE
0.8 x 0.8 x 0.8 mm
9:02



DL 3T EDGE
1 x 1 x 1 mm
4:44

A case example illustrating the comparison of image quality, noise, contrast uniformity, and acquisition speed between standard 3T, standard 7T, and 3T DL EDGE MRI

KEY TEACHING POINTS



The 3D-EDGE improves visualization and detection of subtle cortical boundary lesions by creating signal voids at the grey matter (GM)-white matter (WM) boundary.



Allows improved detection of Type I and Type IIa FCDs that are more difficult to detect on traditional MRI sequences.



The 3D-EDGE sequence also highlights other GM-WM junction abnormalities, such as subcortical laminar heterotopia and temporal pole blurring.



Application of deep learning (DL) image reconstruction allows improvements in scan time and image quality versus traditional acceleration techniques. This is a widely available alternative to 7T EDGE MRI with no B1+ transmit inhomogeneity.

REFERENCES

1. Middlebrooks EH, Ver Hoef L, Szaflarski JP. Neuroimaging in Epilepsy. *Curr Neurol Neurosci Rep*. 2017;17(4):32.
2. Boulby PA, Symms MR, Barker GJ. Optimized interleaved whole-brain 3D double inversion recovery (DIR) sequence for imaging the neocortex. *Magn Reson Med*. 2004;51(6):1181-6.
3. Middlebrooks EH, Lin C, Westerhold E, Okromelidze L, Vibhute P, Grewal SS, et al. Improved detection of focal cortical dysplasia using a novel 3D imaging sequence: Edge-Enhancing Gradient Echo (3D-EDGE) MRI. *Neuroimage Clin*. 2020;28:102449.
4. Urbach H, Kellner E, Kremers N, Blümcke I, Demerath T. MRI of focal cortical dysplasia. *Neuroradiology*. 2022 Mar;64(3):443-452.
5. Abula Y, Abulimiti A, Liu Z, Yimiti Y, Abula Y, Jiang L, et al. The Role of the Three-Dimensional Edge-Enhancing Gradient Echo Sequence at 3T MRI in the Detection of Focal Cortical Dysplasia: A Technical Case Report and Literature Review. *Neuropediatrics*. 2022;53(6):436-9.
6. Okromelidze L, Gupta V, Jain A, Gopal N, Feyissa AM, Tatum WO 4th, Quiñones-Hinojosa A, Grewal SS, Middlebrooks EH. Temporal pole blurring in temporal lobe epilepsy revealed by 3D Edge-Enhancing Gradient Echo MRI. *Neuroradiol J*. 2024 Jun;37(3):386-389.
7. Tao S, Zhou X, Greco E, Gupta V, Freund BE, Westerhold EM, et al. Edge-Enhancing Gradient-Echo MP2RAGE for Clinical Epilepsy Imaging at 7T. *AJNR Am J Neuroradiol*. 2023;44(3):268-70.
8. Middlebrooks EH, Greco E, Zhou X, Gupta V, Freund BE, Agarwal AK, et al. Edge-Enhancing Gradient Echo MRI at 7T for detection of focal cortical dysplasia in epilepsy. *Neuroimage: Reports*. 2023;3(4):100187.
9. Suh PS, Park JE, Roh YH, Kim S, Jung M, Koo YS, et al. Improving Diagnostic Performance of MRI for Temporal Lobe Epilepsy With Deep Learning-Based Image Reconstruction in Patients With Suspected Focal Epilepsy. *Korean J Radiol*. 2024;25(4):374-83.
10. Liu Z, Patel V, Zhou X, Tao S, Yu T, Ma J, et al. Deep-Learning Reconstruction for 7T MP2RAGE and SPACE MRI: Improving Image Quality at High Acceleration Factors. *AJNR Am J Neuroradiol*. 2025.

THANK YOU

Arora.Manasi@mayo.edu

Middlebrooks.Erik@mayo.edu

