MR imaging in epilepsy: Technique and Findings

Maarten Lequin
Department of Radiology & Nuclear Medicine
University Medical Center Utrecht, The Netherlands
Introduction

• 4th most common nontraumatic neurologic disorder
• Worldwide 50 million people have epilepsy
• 30-40% refractory to medical treatment
• Focal epilepsy can be treated with neurosurgery
Neurosurgery

• Success is directly correlated to complete resection
• Surgery is more effective when a structural lesion is found on MRI
• Resection of nonlesional tissue influences cognitive and memory function
epilepsy surgery in MRI-negative patients

truly MRI-negative?

standard vs. epilepsy protocol

higher field strength

new sequences

post-processing
Standard magnetic resonance imaging is inadequate for patients with refractory focal epilepsy

123 epilepsy surgery candidates
standard MRI, "non-expert" radiologists: 39%
standard MRI, epilepsy "expert" radiologists: 50%
dedicated MRI, epilepsy "expert" radiologists: 91%

sensitivity focal lesions
MRI – standard epilepsy imaging protocol (1.5T, 3T)

• s 3D T1
• s 3D T2 (< 2y)
• s 3D FLAIR (> 2y)
• t DWI (t DTI)
• t SWI

• s 3D T1 gado

Saini J, Epilepsia 2009
Duncan JS, Lancet Neurol 2016
SWI
Diffusion weighted imaging (DWI)

- differential diagnosis
- lateralization of epileptogenic focus

- ADC measurements
  - interictal: increased diffusivity in epileptogenic focus/zone
  - ictal: decreased diffusivity in epileptogenic focus/zone
  - postictal: complex patterns

- cave: contradictory results!

Stylianou P, JOCN 2016
Technique

• Gadolinium?

• Not useful in patients with chronic seizures
• Exceptions are patients with known or suspected tumors or neurocutaneous syndromes
• New-onset seizures may require contrast-enhanced imaging
truly MRI-negative?

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higher field strength

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post-processing
### Table 4: Comparison of Lesion Identification and Characterization at 1.5 T and 3 T

<table>
<thead>
<tr>
<th>Result</th>
<th>( p(3 \text{ T vs 1.5 T}) )</th>
<th>Odds Ratio (3 T vs 1.5 T)</th>
<th>95% CI for Odds Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesion identification</td>
<td>0.0364</td>
<td>2.574</td>
<td>1.062–6.240</td>
</tr>
<tr>
<td>Lesion characterization</td>
<td>0.0194</td>
<td>2.664</td>
<td>1.172–6.055</td>
</tr>
</tbody>
</table>

![Brain MRI images](image-url)
Ultra high field strength

• improved delineation lesions in 33% of epileptic patients
• detection of a new lesion in 65% of epileptic patients

Knake S, Neurology 2005
Garbelli R, Neurology 2011
MRI – advanced imaging techniques

• Double inversion recovery (DIR)
• Perfusion weighted imaging (PWI)
  – arterial spin labeling (ASL)
• Diffusion tensor imaging (DTI)
• fMRI

Stylianou P, JOCN 2016
Duncan JS, Lancet Neurol 2016
De Santis S, Magn Reson Imaging 2011
Technique

• Double inversion recovery (DIR):
  – improved lesion-to-background contrast
  – suppression of signal from cerebrospinal fluid
  – suppression of signal from normal white matter
Double Inversion Recovery (DIR)

significantly higher SNR and CNR on DIR!

Li Q, J Assist Comput Tomogr 2011
Zhang Q, J Assist Comput Tomogr 2011
Arterial Spin Labeling (ASL)

15y boy, NF1, with right sided focal seizures

Ictal phase: hyperperfusion
Post-ictal: hypoperfusion
Inter-ictal: heterogeneous
Diffusion Tensor Imaging (DTI)

- tractography
- predicting postoperative deficit
- guiding surgery preoperatively
- Post-operative evaluation

© Tax CMW, PlosOne 2014
Stylianou P, JOCN 2016
Szmuda M, Neurol Neuroch Pol 2016
Functional MRI (fMRI)

- Blood oxygen level dependent fMRI (BOLD-fMRI)
- Presurgical planning:
  - language lateralization (94% concordance with Wada test)
  - sensory & motor functions
    - invasive presurgical electrocortical stimulation mapping gold standard

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Stylianou P, JOCN 2016
Duncan JS, Lancet Neurol 2016
patients • new insights on the functional architecture of the healthy brain. • Various RSNs, or collections of regions that have synchronous spontaneous BOLD fluctuations, have been identified, including the DMN and sensorimotor, visual, and attentional networks.

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Stylianou P, JOCN 2016
IS, Lancet Neurol 2016
Hong et al, 2013

Controls FCD-II HET PMG

Nodes Rich club Peripheral

Edges Rich club Feeder Local

truly MRI-negative?

standard vs. epilepsy protocol

higher field strength

new sequences

post-processing
MRI – post-processing techniques

- Quantitative MRI/post-processing techniques
  - T1/T2 relaxometry (hippocampus)
  - whole brain T2 mapping
  - volumetric measurements (hippocampus)
  - voxel-based morphometry
  - texture-based analysis

Stylianou P, JOCN 2016
Kini LG, Neuroimage 2016
Duncan JS, Lancet Neurol 2016
voxel based morphometry (VBM) - FCD


3D T1 normalized to MNI space, GM/WM segmentation, VBM/SPM control template MAP,
3D z-score maps, GM extension, GMWM blurring
Disorders of the brain with a clinically manifested liability to epileptic seizures

- Vascular malformation
- Mechanical trauma
  - Meningitis
  - Encephalitis
- Infection
- Chemical imbalance
- Metabolic disease
- Structural abnormalities
  - Cerebral tumours
  - Malformations of cortical development
  - Birth asphyxia
  - Hypoxic ischemic injury
  - Cerebrovascular insult

Metabolic diseases: Birth asphyxia, Hypoxic ischemic injury, Cerebrovascular insult, Malformations of cortical development, Birth asphyxia, Metabolic disease
Mesial Temporal Sclerosis

• Most common cause of partial complex epilepsy
• Hippocampal volume loss -> neuronal loss – atrophy
• Hippocampal hyperintensity -> gliosis - seen on T2/FLAIR
• In 15 % of patients another developmental abnormality can be found: frequently focal cortical dysplasia
Mesial Temporal Sclerosis
Mesial Temporal Sclerosis
Mesial Temporal Sclerosis
Malformations of Cortical Development

- Group I: abnormal cell proliferation or apoptosis
- Group II: abnormal neuronal migration
- Group III: abnormal cortical organization

- Separate classification for focal cortical dysplasia.....
Group I: abnormal cell proliferation or apoptosis

- Group I.A
  - microcephaly
    - with normal to simplified cortical pattern
    - microcephaly with lissencephaly
    - microcephaly with extensive polymicrogyria

- Group I.B
  - megalencephaly/macrocephaly
Lissencephaly
Group I: abnormal cell proliferation or apoptosis

• Group I.C: cortical dysgenesis with abnormal cell proliferation
  – Non-neoplastic:
    • cortical hamartomas of tuberous sclerosis
    • cortical dysplasia with balloon cells
    • hemimegalencephaly
    • type II focal cortical dysplasia
  – Neoplastic:
    • dysembryoplastic neuroepithelial tumours (DNET)
    • gangliogliomas
    • gangliocytomas
Tuberous Sclerosis

• Cerebral tubers:
  – Cortical/subcortical lesion expanding overlying gyrus
  – T2/FLAIR hyperintense, T1 hypointense after myelination
  – T1 hyperintense prior to myelination
Tuberous Sclerosis
Tuberous Sclerosis

• Subependymal nodules (SENs):
  – Elongated nodules in locations of fetal germinal matrix
  – Increasing Ca++ over time
  – 30-80% enhance

• Subependymal giant cell astrocytoma (SEGA):
  – Growing nodule at caudothalamic groove
Tuberous Sclerosis
DNET (Dysembryoplastic neuroepithelial tumor)

- Swollen gyrus
- Bubbly cystic appearance
- Usually no or only little enhancement
- Associated with focal cortical dysplasia
Group II: abnormal neuronal migration

- Group II.A
  - subependymal heterotopia
  - marginal glioneuronal heterotopia
- Group II.B
  - lissencephaly type I: subcortical band heterotopia spectrum (band heterotopia): under migration
  - lissencephaly type II (cobblestone complex): over migration
- Group II.C
  - subcortical heterotopia (not including band heterotopia)
Subependymal Heterotopia
Band Heterotopia
Group III: abnormal post migrational development

• Group III.A
  – polymicrogyria and schizencephaly
    • bilateral polymicrogyria syndromes
    • schizencephaly
    • polymicrogyria or schizencephaly as part of multiple congenital anomaly/mental retardation syndromes
Polymicrogyria and schizencephaly
Focal cortical dysplasia

- Taylor dysplasia (1971)
- Palmini classification (2004)
- Barkovich classification (2005)
- Blumcke classification (2011)
Focal cortical dysplasia

- Cortical thickening
- Blurring of grey-white matter junction
- Increased subcortical T2 signal intensity
- Transmantle sign (abnormal function of, or injury to radial glial fibers)
Minor Malformations of Cortical Development (mMCD)
- mMCD Type I - ectopically placed neurons in Layer 1
- mMCD Type II - microscopic heterotopia outside Layer 1

- FCD Type I - Dyslamination of Cerebral Cortex
  "Type Ia - vertical dyslamination"
  "Type Ib - horizontal dyslamination"
  "Type Ic - vertical and horizontal dyslamination"

- FCD Type II - Dysmorphic neurons +/- balloon cells
  "Type IIa - dysmorphic neurons without BC"
  "Type IIb - dysmorphic neurons with BC"

- FCD Type III - Type I FCD with associated lesion: MTS (IIIa),
  tumor (IIIb), vascular malformation (IIIc), prior infection/injury (IIIId)
8 mo with Infantile Spasms

Absent subcortical Myelin, reduced FDG uptake.

Dx: FCDla

FCD Type I
Focal cortical dysplasia
Transmantle sign
Cortical and Glial Scars

• Infarction
• Hemorrhage
• Trauma
Infarction
Trauma
Cavernoma

- "Popcorn ball" with hemosiderin rim
- T2* and SWI
- Punctuated hypointense foci (black dots)
- Look for associated DVA if single
Cavernoma
Encephalitis

- Viral
- Auto-immune
- Rasmussen
Herpes Encephalitis
Limbic Encephalitis
Rasmussen Encephalitis

- Chronic focal encephalitis
- Unilateral cortical atrophy without enhancement
- Functional hemispherectomy is the only definitive treatment
Conclusion

• Patient age and history are key
• Imaging is essential
• Proper imaging is more essential
• Proper image evaluation is most essential
MRI presurgical evaluation: presumed structural epilepsy

SCN1A  JME  PCDH19

genetic / idiopathic epilepsy syndrome: rejected for surgery
take home messages

• 1.5T > 3T > 7T
• thin slices > volumetric imaging
  – parallel/orthogonal angulation to hippocampal plane
• post-processing techniques
  – surface rendering techniques
  – computer-based analytic methods
• advanced imaging techniques
  – diffusion tensor imaging (DTI)
  – Resting state fMRI
Thank you for your attention!

Acknowledgements:
- Tim Veersema
- Tom Snijders
- Floor Jansen
- Kees Braun
Cases
Term neonate
day 6 seizures
Diagnosis?

KCNQ2 mutation
Boy, 8y, medically refractory epilepsy

PA: ganglioglioma, WHO grade 1
Epilepsy-associated developmental tumors

- ganglioglioma
- gangliocytoma
- desmoplastic infantile ganglioglioma
- dysembryoplastic neuroepithelial tumor (DNET)
- pleomorphic xanthoastrocytoma
Epilepsy-associated developmental tumors

Gangioglioma & FCD

can be associated with developmental anomalies!

Rastogi S, Radiographics 2008
Boy, 14y, Tuberous Sclerosis, normal IQ and development, multiple seizure types, age at onset 6.5y
Tuberous sclerosis complex (TSC)

- medically refractory epilepsy
  - surgical removal increasingly recommended
  - marked reduction in seizures if localization of onset can be restricted to a single lesion/area
  - multimodal approach needed for presurgical planning
Interictal EEG and MEG

- multifocal epileptiform activity (both hemispheres)
- hypofunction R posterior temporal lobe
- normal representation of handfunction

Courtesy of F. Jansen, Utrecht
99mTc-HMPAO SPECT

Interictal

Ictal

SPECT

SPECT-MRI

T1 gd

Courtesy of F. Jansen, Utrecht
SISCOM and seizure onset

Courtesy of F. Jansen, Utrecht
Multimodality approach

- Grid implantation
- EEG, MEG
- MRI
- (inter)ictal SPECT

- running seizures R temporal
- subclinical seizures lesion R frontal lobe

Courtesy of F. Jansen, Utrecht
Surgery and post-surgical follow up

• Surgery:
  – lesionectomy R frontal
  – lobectomy R temporal

• Follow up (9m):
  – no type 1 seizures
  – weekly visual signs
  – more alert, QoL↑↑
  – shows emotion

Courtesy of F. Jansen, Utrecht
Boy, 14y, right-handed, refractory epilepsy, EEG: epileptogenic focus L frontal lobe

Courtesy of T. Veersema, Utrecht
18F-FDG PET/CT

Courtesy of T. Veersema, Utrecht
Magneto-encephalography (MEG)

- epileptogenic focus L frontal lobe

Courtesy of T. Veersema, Utrecht
7T MRI

Courtesy of T. Veersema, Utrecht
7T MRI

Courtesy of T. Veersema, Utrecht
MEG & MRI coregistration

Courtesy of T. Veersema, Utrecht
Invasive EEG: Subdural grid electrodes

Courtesy of T. Veersema, Utrecht