Diffusion-Weighted Imaging (DWI) with dual-echo EPI for better sensitivity to acute stroke and brain injury

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Outline

DWI is the gold standard for acute stroke imaging, but short TEs of routine DWI limit its sensitivity for acute lesions.

Acute stroke shows restricted diffusion

Introduction and limitation of current DWI imaging
• Dual-echo EPI DWI approach (Echo 1 and Echo 2)
• Clinical examples
• Potential limitations
• Suggested clinical use
• Additional bonuses of dual-echo EPI DWI (R₂ map, coil-sensitivity corrected DWIs)

DWI in the clinics

• Standard DWI uses the Echo Planar Imaging (EPI) technique

How DWI is read by radiologists

• Acute stroke: High on DWI, Low on ADC ("diffusion restricting" lesion)
• Chronic stroke: High on DWI, High on ADC
• Reduced ADC or "diffusion restricting" suggesting acute stroke

Common Teaching in DWI

• "use the shortest TE to avoid additional T2 contrast (i.e. 'T2-shine through'"

Problem with short TEs

• But, many diffusion restricting lesions also have a prolonged T₂ [1]
⇒ using short TEs to reduce T2 contrast, may actually reduce the conspicuity of ischemic lesions.


DWI (b = 1000 s/mm²)
ADC

ADC shows restricting and unrestricting lesions

Reduced ADC suggesting acute stroke

Benefit of a long TE

Better lesion conspicuity with longer TE

Possible better approach to DWI?

- Standard DWI uses the EPI technique
- To improve lesion conspicuity, add a later echo in the same TR

Methods: Dual Echo DWI

- 50 patients suspected of stroke were scanned
  - 1.5T MRI (GE) system, 8-ch head coil
  - GRAPPA (3-shot) interleaved EPI sequence
  - 4 b = 1000s/mm², 1 b=0
  - FOV = 24x24cm, matrix size = 102x102, slice = 5 mm, TR = 3s, TE1/TE2 = 51ms/115ms
  - scan time = 2:15min. No cost in scan time c.f. single echo

Analysis of Echo 1 and Echo 2

Grading of Echo 1 and Echo 2
- Diagnostic confidence
- Lesion conspicuity
  - 3 radiologists independently reviewed the DW images
  - Grading method: 1=nondiagnostic, 2-poor, 3-acceptable, 4-average, 5–above average, 6–very good, 7–outstanding.

Clinical impact of Echo 2
  1) Further work-up (new study, cardiac echo, carotid U/S)
  2) Initiation of medications

61yr male, contusion & hemorrhage

DWI: Echo 1
ADC shows restricted diffusion

Results
Tumor resection cases

39yr male, Moya Moya

DWI: Echo 1
ADC shows restricted diffusion

DWI: Echo 2
ADC shows restricted diffusion

Acute post-operative ischemic injury presenting with acute stroke-like symptoms. Scattered infarcts are more conspicuous on Echo 2. Also note nice distinction of small subdural hematoma on Echo 2.

88yr female, rule out stroke

DWI: Echo 1
ADC shows restricted diffusion

DWI: Echo 2
ADC shows restricted diffusion

A missed focal lesion in the corpus callosum. Originally a negative study. Echo 2 changed clinical impression and impact (need to work up the heart – could be embolic infarct).

66yr female, embolic stroke

DWI: Echo 1
ADC shows restricted diffusion

DWI: Echo 2
ADC shows restricted diffusion

Additional embolic infarct on the left frontal cortex.

69yr male, stroke

DWI: Echo 1
ADC shows restricting and unrestricting lesions

DWI: Echo 2
ADC shows restricting and unrestricting lesions

Echo 2 shows strokes of different ages (dark areas on ADC considered more subacute or chronic, probably due to edema). Echo 2 has reduced specificity as it brings out bright diffusion lesions. However, our radiologists rated Echo 2 higher for diagnostic confidence in these complex cases due to its increased overall lesion conspicuity.

Lesion count

Out of 50 patients:
- 36 had diffusion lesions
- 14 normals

Lesion Conspicuity:
- A total of 72 new lesions were identified on Echo 2 (seen in 24 patients)
- Not only was Echo 2 more sensitive, but it also showed very high specificity for acute lesions.
Clinical impact

Clinical impact of Echo 2
- 8 patients: would have changed clinical course
- 16 patients: would have explained presenting symptoms but not have altered clinical course

Radiologists’ grading

<table>
<thead>
<tr>
<th>Radiologist’s grading</th>
<th>Echo 1</th>
<th>Echo 2</th>
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<tbody>
<tr>
<td>7 – outstanding</td>
<td></td>
<td></td>
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<tr>
<td>6 – very good</td>
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<tr>
<td>5 – above average</td>
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<tr>
<td>4 – comparable</td>
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<tr>
<td>3 – below average</td>
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<tr>
<td>2 – poor</td>
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<tr>
<td>1 – non-diagnostic</td>
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Holdsworth S.J. et al.
Dual echo DW-EPI for better sensitivity to acute stroke. ISMRM 2013

Results

Radiologists’ grading

Dual Echo DWI: suggested use

- DWI of Echo 2:
  - Used for lesion sensitivity
- ADC of Echo 1
  - for higher maps
  - Acute ischemia confirmation

DWI should always be evaluated in conjunction with ADC maps to distinguish true restriction (high on DWI and low on ADC) from lesions with “T2 shine-through” (high on both DWI and ADC).

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Bonus of dual-echo EPI DWI: Relaxivity maps

- Bonus: calculate $R_2$ maps from the two echoes

$R_2 = 1/T_2$

$R_2$ map

- $R_2$ map more sensitive for calcification and blood products.
- Though role of $R_2$ map yet to be elucidated.
Another bonus of dual-echo EPI DWI: Coil Sensitivity Correction

Can calculate coil sensitivity-corrected maps, which remove the hyperintensity of the signal—particularly in the posterior regions where cortical regions are closer to individual coil elements.

11yr old female: Medulloblastoma

- posterior fossa brain tumor (medulloblastoma)

11yr old female: Medulloblastoma

- DWI: Echo 1
- DWI: Echo 2
- Corrected DWI: Echo 2

The mass shows characteristic reduced diffusion due to tumor cellularity. Note higher contrast on Echo 2. Coil sensitivity image reduces the bright artifact in the cerebellum.

7 day old infant: Multiorgan failure

- presents with seizures. Patient has multiple hemorrhages and areas of brain injury

7 day old infant: Multiorgan failure

- DWI: Echo 1
- DWI: Echo 2
- Corrected DWI: Echo 2

Note focal injury/ischemia is brighter and better detected on Echo 2 (arrow). On coil sensitivity-corrected Echo 2 image, a reduction in artifact in the posterior brain region can be seen, which better unmasks regions of DWI abnormality (combination of hemorrhage/ischemia) (arrowhead).

Posterior Reversible Encephalopathy Syndrome (PRES)

- 8-year old girl with hypertension presenting with PRES. MRI shows characteristic FLAIR high intensity in the cortical/subcortical brain.
Conclusion: Benefits of dual-echo EPI DWI imaging

- An additional echo at a later TE is useful for
  - Better lesion conspicuity and detection (Echo 2)
  - Higher SNR ADC map from Echo 1
- No scan time penalty (assuming the use of TR$_{min}$ = 3 for full T1 recovery)
- Caveat of dual echo EPI DWI: mildly reduced specificity
  - ≤7% of lesions were indeterminant (T2-shine through or too small)
  - Nevertheless, Echo 2 was preferred by radiologists due to increased sensitivity & confidence.
- Additional bonuses of dual echo EPI DWI:
  - R2 maps: may provide complementary information (blood and calcium)
  - Coil-sensitivity-corrected DWI maps: useful for removing inhomogeneous signal

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