Abdominal applications of DWI

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Outline

• **What** is DWI?
• **How** to perform?
  • *Challenges*
  • *Technique*
• **When** to use?
  • *Indications*
What is DWI?

Brownian motion

DWI and body water spaces

Consider DWI signal from tissue to arise from water protons in 3 different compartments:

- Intra-vascular
- Intra-cellular
- Extra-cellular
What is DWI?

Normal tissue

Pathology
## How to perform?

### Challenges

<table>
<thead>
<tr>
<th>Low spatial resolution</th>
<th>Artifacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>low matrix</td>
<td>motion artifacts</td>
</tr>
<tr>
<td>low SNR (high b-values)</td>
<td>(respiratory, cardiac)</td>
</tr>
<tr>
<td></td>
<td>uneven fat saturation</td>
</tr>
<tr>
<td></td>
<td>susceptibility artifacts</td>
</tr>
</tbody>
</table>

### Quantification (ADC)
**How to perform?**

**Technique optimization**

- **Hardware**
  - Magnetic field
  - Coils

- **Scan technique**
  - NEX
  - Fat suppression
  - Breathing techniques
  - b-values
Hardware

• High magnetic field
  • 1.5T or 3T

• Coils
  • Integrated quadrature body coil
  • Phased array surface coils
Number of excitations (NEX)

```
<table>
<thead>
<tr>
<th>B-value (s/mm$^2$)</th>
<th>NEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>150</td>
<td>3</td>
</tr>
<tr>
<td>500</td>
<td>3</td>
</tr>
<tr>
<td>1000</td>
<td>3</td>
</tr>
</tbody>
</table>
```

"NEX = 3"
Number of excitations (NEX)

Improvement of SNR without increase in scantime!

NEX adjusted for each b-value

<table>
<thead>
<tr>
<th>B-value</th>
<th>NEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>150</td>
<td>2</td>
</tr>
<tr>
<td>500</td>
<td>3</td>
</tr>
<tr>
<td>1000</td>
<td>6</td>
</tr>
</tbody>
</table>
Fat suppression

- STIR
- SPAIR
- SSGR
- …
Fat suppression

Peritoneal metastasis from ovarian carcinoma

Gd-FS-T1-weighted

DWI-fat sat

DWI-STIR
Fat suppression

Best fat suppression was achieved using STIR with SSGR (≥3T)

Horie et al. ISMRM 2009
Breathing techniques

• Breath-hold

• Respiratory gating
  • *Tracking Only Navigator* (TRON)

• Free-breathing
Breathing techniques

- **Breath-hold**
  - Fast assessment of target volume (10-20s)
  - Less motion/volume averaging
  - Thick slices (8-10 mm)
  - Limited no. of b-values and signal averages
Breathing techniques

• Breath-hold
  + Fast assessment of target volume (10-20s)
  + Less motion/volume averaging
  • Thick slices (8-10 mm)
  • Limited no. of b-values and signal averages

• Respiratory gating
  + Thin slices (4 mm)
  + Multiple b-values and signal averages
  + Less motion/volume averaging
  • Longer scan times
Respiratory gating

Tracking Only Navigator (TRON)

Continuous data acquisition and position correction

Takahara T, Kwee TC, et al. Invest Radiol 2010;45:57-63
TRacking Only Navigator (TRON)

Conventional navigator

TRON

gating window

only tracking is done

all data are accepted

Takahara T, Kwee TC, et al. Invest Radiol 2010;45:57-63
Respiratory gating

195 sec

- Long scan times

+ Sharp images

TRON

71 sec

+ Short scan times

+ Sharp images

Takahara T, Kwee TC, et al. Invest Radiol 2010;45:57-63
Breathing techniques

• Breath-hold
  + Fast assessment of target volume (10-20s)
  + Less motion/volume averaging
  • Thick slices (8-10 mm)
  • Limited no. of b-values and signal averages

• Respiratory gating
  + Thin slices (4 mm)
  + Multiple b-values and signal averages
  + Less motion/volume averaging
  • Longer scan times

• Free breathing
  + Thin slices (4 mm)
  + Multiple b-values and signal averages
  + Reasonable scan times
  • Motion/volume averaging
Free breathing vs. breath-hold

Axial 8 mm breath-hold

Axial 4 mm free breathing

Sagittal MPR 5 mm

Resp. triggering

Free breathing (DWIBS)


*Inverted display
B-values

For visual assessment:
• typically higher b-values (750-1000 s/mm²) to maximize background suppression

For quantifying ADC:
• 2 or more b-values
• low b-value of 50-150 s/mm² to minimize perfusion effects on the ADC
• high b-value of 500-1000 s/mm²
B-values

Typical high b-values (s/mm²) used in the body:

- **Head & Neck**: 600 - 1000
- **Breast**: 600 - 1000
- **Lung**: 600 - 1000
- **Liver**: <100 (black blood)/500 - 700
- **Kidneys**: 600 - 1000
- **Pelvis**: 600 - 1000
- **Prostate**: 1000 - 2000
Lesion detection: liver metastases

Apply a low b-value for liver lesion detection!

Takahara T & Kwee TC. J Magn Reson Imaging 2012;35:1266-1273
Lesion detection: liver metastases

- Sensitivity DWI superior to that of T2-weighted imaging
  - 86.4% vs. 62.9% for malignant lesion detection*

**B-values**

For visual assessment:
- typically higher b-values (750-1000 s/mm²) to maximize background suppression

For quantifying ADC:
- 2 or more b-values
- low b-value of 50-150 s/mm² to minimize perfusion effects on the ADC
- high b-value of 500-1000 s/mm²
Perfusion sensitive ADC

Rapid initial decrease in signal with increasing b-value is due to signal attenuation of capillary perfusion. The slope of the best fit line through all b-values (---) represents a perfusion sensitive ADC.

Perfusion insensitive ADC

The slope of the line plotted only through higher b-values (150 - 500) represents a perfusion insensitive ADC.
Role of ADC measurements

- systematic review
- mean quality score: 50%
- marked variation ADC
  - among studies
  - between benign/malignant lesions
- value of ADC measurements:
  - good discrimination: breast, liver, uterus
  - no significant difference: salivary glands, thyroid, pancreas
- standardisation acquisition protocols and reporting

Role of ADC measurements

- systematic review
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When to use?

- Staging (and follow up) of malignant diseases
  - *haematological malignancies (lymphoma)*
  - *solid tumors (metastatic spread)*
- Inflammatory and infectious diseases
  - *inflammatory bowel disease (IBD)*
  - *appendicitis*
  - *fluid collections*
  - ....
Burkitt lymphoma – staging

• example
Neuroblastoma – staging

• example
Neuroblastoma – follow up

• example
DWI - staging

- preliminary results  multicenter study - Utrecht
Animal study: quantitative analysis

**CHOPB-induced ADC changes**

- Increase mean ADC as early as 1 week
- Concomitant volume changes!

**CHOPB-induced volume changes**

*Huang MQ. NMR Biomed 2008;21:1021-1029*
DWI: early response assessment

Human study: quantitative analysis

Chemotherapy-induced ADC changes

Before therapy: significant
1 week: significant
After therapy: significant

Chemotherapy-induced diameter changes

Before therapy: not significant
1 week: significant
After therapy: significant

Chen Y. Magn Reson Imaging 2012;30:165-170
Inflammatory bowel disease (IBD)

- Crohn’s disease (n=33)
- Matched controls (n=27)
- 1.5T: CE-T1W, DWI

- DWI correctly identified 32/33 patients
- CE-T1W correctly identified 31/33 patients
- False-positive findings
  - DWI n=2, CE-T1W n=1
  - collapsed large bowel lumen

Inflammatory bowel disease (IBD)

# Inflammatory bowel disease (IBD)

**Table 3** ADC$_{\text{total}}$ 50/800 in various organs, body fluids and normal distended bowel wall in patients and controls and in inflamed bowel wall in patients

<table>
<thead>
<tr>
<th></th>
<th>ADC (10^{-3} \text{mm}^2/\text{s})</th>
<th>Mean</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Internal reference</strong> (patients and controls)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muscle</td>
<td>1.22±0.09</td>
<td>1.03–1.41</td>
<td></td>
</tr>
<tr>
<td>Liver</td>
<td>1.10±0.08</td>
<td>0.92–1.32</td>
<td></td>
</tr>
<tr>
<td>Spleen</td>
<td>0.84±0.08</td>
<td>0.65–1.02</td>
<td></td>
</tr>
<tr>
<td>Kidney</td>
<td>1.85±0.09</td>
<td>1.65–2.07</td>
<td></td>
</tr>
<tr>
<td>Renal pelvis</td>
<td>3.21±0.43</td>
<td>2.26–4.28</td>
<td></td>
</tr>
<tr>
<td>CSF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urinary bladder</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Normal distended bowel wall (patients and controls)**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Small bowel</td>
<td>2.08±0.16</td>
<td>1.77–2.44</td>
</tr>
<tr>
<td>Large bowel</td>
<td>2.01±0.14</td>
<td>1.61–2.24</td>
</tr>
</tbody>
</table>

**Inflamed bowel wall (patients only)**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Small bowel</td>
<td>1.16±0.18</td>
<td>0.84–1.40</td>
</tr>
<tr>
<td>Large bowel</td>
<td>1.21±0.21</td>
<td>0.84–1.60</td>
</tr>
</tbody>
</table>

Inflammatory bowel disease (IBD)

- Crohn’s disease (n=18)
- MR enterography
  - $dCE-T1W$, $DWI$
  - AUROC: $K_{trans}$, $V_e$, ADC 0.88-0.92
  - $K_{trans} + $ ADC 0.95

Table 3

<table>
<thead>
<tr>
<th></th>
<th>Normal ileal loop</th>
<th>Terminal ileum</th>
<th>t-test analysis</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Active CD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$K_{trans}$ (min$^{-1}$)</td>
<td>0.36 ± 0.19</td>
<td>0.02 ± 0.12</td>
<td>-</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>$V_e$</td>
<td>0.15 ± 0.08</td>
<td>0.01 ± 0.01</td>
<td>-</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>ADC ($\times 10^{-3}$ mm$^2$/s)</td>
<td>3.11 ± 0.56</td>
<td>0.31 ± 0.11</td>
<td>-</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td><strong>Inactive CD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$K_{trans}$ (min$^{-1}$)</td>
<td>0.18 ± 0.13</td>
<td>0.17 ± 0.16</td>
<td>-</td>
<td>0.14</td>
</tr>
<tr>
<td>$V_e$</td>
<td>0.12 ± 0.06</td>
<td>0.11 ± 0.00</td>
<td>-</td>
<td>0.01</td>
</tr>
<tr>
<td>ADC ($\times 10^{-3}$ mm$^2$/s)</td>
<td>2.48 ± 0.63</td>
<td>2.48 ± 0.63</td>
<td>-</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Appendicitis

- clinically acute appendicitis, n=119 (33-69y)
- healthy controls, n=50
- DWI, visual and quantative evaluation
- histopathology + in 79/92 patients (surgery)

- Visual evaluation: 78/79 (98.7%)
- Quantative evaluation
  - intensity (b500): cut-off 56, sen 99%, spec 97%
  - ADC: cut off 1.66 mm2/s, sen 97%, spec 99%

## Appendicitis

<table>
<thead>
<tr>
<th></th>
<th>Normal appendix (Healthy control group, n=50)</th>
<th>Normal appendix (Patient group, n=40 (27+13))</th>
<th>Inflamed appendix (n=79)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>b 0 (s/mm²)</td>
<td>(81±32)</td>
<td>85±23</td>
<td>304±85</td>
<td>0.001</td>
</tr>
<tr>
<td>b 500 (s/mm²)</td>
<td>(36±16)</td>
<td>39±14</td>
<td>114±38</td>
<td>0.001</td>
</tr>
<tr>
<td>b 1000 (s/mm²)</td>
<td>(19±11)</td>
<td>21±7</td>
<td>67±28</td>
<td>0.001</td>
</tr>
<tr>
<td>ADC (×10⁻³ mm²/s)</td>
<td>(2.02±0.19)</td>
<td>2.04±0.14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abdominal fluid collections

- suspected abscess: n=17 (13 ± 6 years)
- age-matched controls: n=17
- MRI: CE-T1W, DWI
- ADC:
  - 13/14: < 1.0 x 10^{-3} mm^2/s
  - 1/14: 1.85 x 10^{-3} mm^2/s (tuberculous abscess)
- Ring enhancement:
  - 3 non-purulent fluid collections

# Abdominal fluid collections

**Table 1. Mean apparent diffusion coefficient (ADC) of various tissues and fluids measured in study patients and controls**

<table>
<thead>
<tr>
<th>Tissue</th>
<th>n</th>
<th>Mean ADC values, $\times 10^3$ mm$^2$/s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Abscess*</td>
<td>13</td>
<td>0.80</td>
</tr>
<tr>
<td>Muscle</td>
<td>24</td>
<td>1.19</td>
</tr>
<tr>
<td>Liver</td>
<td>17</td>
<td>1.13</td>
</tr>
<tr>
<td>Spleen</td>
<td>13</td>
<td>0.88</td>
</tr>
<tr>
<td>Renal cortex</td>
<td>21</td>
<td>1.80</td>
</tr>
<tr>
<td>Renal pelvis</td>
<td>16</td>
<td>3.17</td>
</tr>
<tr>
<td>Free abdominal fluid</td>
<td>26</td>
<td>3.19</td>
</tr>
<tr>
<td>Urinary bladder</td>
<td>26</td>
<td>3.14</td>
</tr>
<tr>
<td>Cerebrospinal fluid</td>
<td>28</td>
<td>3.51</td>
</tr>
</tbody>
</table>

*: only confirmed cases of abscess formation (n=13), excluding patients no. 2, 5, 13 and 15.

Abdominal fluid collections

Conclusions

DWI is feasible in children

Lesion detection
Lesion-to-background contrast

Lesion characterization
Functional tissue information

### Conclusions

#### Challenges
- low spatial resolution
  - low matrix
  - Low SNR (↑ b-values)
- artifacts
  - motion
  - fat saturation

#### Technique
- higher magnetic field
- phased array coils
- NEX – b-values
- breathing techniques
  - resp. gating (TRON)
  - free breathing (DWIBS)
- STIR (+ SSGR)

#### Challenges (continued)
- visual assessment: high b-values*
- quantification: > 2 b-values

*only exception: liver lesions
Thank you for your attention!

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