CLINICAL APPLICATIONS OF DIFFUSION-WEIGHTED IMAGING IN THE ABDOMEN

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ABDOMINAL DIFFUSION-WEIGHTED IMAGING

Hepatic imaging
- Non-cirrhotic liver
  - Lesion characterization
  - Detection of metastases
- Cirrhotic liver
  - Tumor versus pseudo-tumor
  - Prediction of lesion progression
  - Transplantation?

Post-treatment imaging
- Abdominopelvic tumors
  - Post-surgical
  - Post-chemoradiation
- Fibrosis versus tumoral recurrence

Extrahepatic imaging
- Primary tumor detection
  - Pancreaticobiliary
  - Endometrial carcinoma
  - Uterine cervical carcinoma
  - Intestinal tumors
  - Prostate cancer
  - Renal cancer
- Staging
  - Lymph nodes
  - Distant metastatic spread
  - Second primary tumors
Differences in microstructure

- Changes in H₂O mobility

*Diffusion-weighted image contrast
- Mathematical quantification
- Apparent diffusion coefficient
- No need for exogenic contrast agent
- No irradiation \(\rightarrow\) magnetic

Worldwide \(\rightarrow\) not routine
- High expertise per centre
  - Research
  - Clinical routine

Facilitated diffusion

Restricted diffusion

Native images: b-value (increasing the sensitivity for impeded diffusion)
Calculated ADC map
Correct shim position: volume shim > auto shim

- High gradient strengths
- Field-strength? 1.5T vs 3T
- Minimal TE
- Maximum Bandwidth
- Realistic spatial resolution: tumor detection
- Volume shim (anteroposterior)
- Volume of interest + edge reserve
- Edge of scan volume increased artefacts
- 3T DWI optimum Minimal
  - Minimal slices 31-36 31-36
  - Distance factor 0% 0%
  - Scan position isocenter isocenter
  - Phase encoding anterior-posterior anterior-posterior
  - FoV read 380 mm 380 mm
  - FoV phase 100% 81%
  - Slice thickness 5 mm 5 mm
  - TR 6600 ms 5100 ms
  - TE 67 ms 84 ms
  - Averages 3 4
  - Concatenations 1 1
  - Fat Suppr SPAIR Fat Sat
  - Fat sat mode strong strong
  - Base resolution 192 128
  - Phase resolution 80% 100%
  - Partial Fourier 7/8 6/8
  - Acceleration factor PE (SENSE-GRAPPA) 2 0
  - Bandwidth 1736Hz/Px 1502
  - EPI factor 154 104

6 good reasons to use a high b-value (b600 → b1000)

Imaging technique: choice of the b-value

Increasing b-value (shutter speed)
CHOICE OF B-VALUE

Diffusion-Weighted Magnetic Resonance Imaging for Characterization of Focal Liver Masses: Impact of Parallel Imaging (SENSE) and b Value

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Similar image quality high vs low b-value
Higher accuracy high vs low b-value

CHOICE OF B-VALUE

• Current criteria in our center → b0-b100-b600-b1000 (free breathing DWI):

  • Lymph nodes: ADC → malignant < 0.001mm²/sec < benign
    • Sens: 76-83%; spec 94%
    • Colorectal, gastro-intestinal and ovarian

  • Non-cirrhotic liver: malignant (b1000+)<0.0011<benign (b1000-/+)
    T2 anatomical correlate

  • Cirrhotic liver: b600 SI + anatomical imaging – contrast-enhanced

  • Skeletal/non-hepatic soft tissue metastasis: b1000+/ anatomical correlate

  • Primary/tumor: b1000+/ anatomical correlate
  • CAVE: pancreatic applications: anatomical correlate and ADC

Major cause for false positives: abscess, hematoma, granuloma – low ADC
BASIC IMAGE INTERPRETATION: TUMOR RECURRENCE

Primary location: b1000 + (ADC) + anatomical correlate
Nodal disease: b1000 + ADC (TH 0.0014)

T2 SHINE THROUGH

T2 shine through (high b-value DWI): Benign lesion with high signal on high b-value images.

- Presence of signal on high b-value DWI is not (always) indicative of malignancy

Remaining issues, under research:
- Granulation tissue (ADC + high b-value)
- Reactive lesions (ADC + high b-value)

False positive b1000

ADC=0.00161
LOW T2
INSUFFICIENT SIGNAL @ B0

- Low ADC values are not (always) indicative of malignancy
  "If there is not enough signal to start from, you cannot lose enough signal to indicate benignity"

False positive ADC

NO CONTRAST LESION TO BACKGROUND

- Similar signal changes between background and tumoral tissue
  Does not allow for primary lesion detection on native DWI

B1000 indeterminate detection
Characterization
**INSUFFICIENT SOLID TUMOR COMPONENT**

Necrosis:
- high T2 – high b0 – low b1000

- High ADC values are not (always) indicative of benignity

- Absence of signal on high b-value DWI is not (always) indicative of benignity
  - Check for irregular rim or dots on b1000

**False negative ADC**
- B1000 heterogeneity

**LIVER IMAGING**

- **Standardize interpretation criteria**
  - Qualitative and quantitative
  - Native b-images > ADC

- **Artefacting**
- **Pitfalls**
- **Clinical indication**

Diffusion-weighted anatomy:
- Normal condition
- Pathologic condition

*Cirrhosis of the river.*
LIVER IMAGING

- Both on clinical indication and methodology a distinct difference should be made between the non-cirrhotic and cirrhotic liver
- Capture all morphologic features on native DWI images for characterization
- ADC is highly dependent of signal variations on b0-b1000
- Main indication in “non-cirrhotic” liver is staging (liver metastases)
- Main indication in “cirrhotic liver” is detection of HCC
- Consider benign lesions as “avoid a false positive”
- Should we really make a difference between lesion detection and characterization
  - If you detect a liver metastasis you are very likely to call it a metastasis

NON-CIRRHOTIC LIVER: ANATOMY

- Segment 5 and 6: adjacent hepatic flexure of colon
- Signal loss
- Distortion artefact
- Due to air tissue interface
- Bile → viscous fluid: Prolonged SI on native DWI

Left lobe:
Cardiac pulse
Base of lung
Signal loss at high b
NON-CIRRHOTIC : DETECTION OF METASTASES

56 patients with primary tumor
Sens = 96.6%
Spec = 93%

Metastases: Native DWI b50-b1000

\[ b_{1000} \rightarrow \text{NPV} > 90\% \]

STOP

\[ b_{1000} + \rightarrow \text{ADC} \rightarrow T_2(T_{263}/T_{263}) \]

Cave necrotic metastases

Native images signal heterogeneity !!!

Metastases – hemangioma – FNH/adenoma
Benign lesions: cyst/hemangioma

Absent signal on b1000 or T2 – shine through - always ADC>0.00120

- Cyst
- Hemangioma

- Cave cavernous hemangioma: may be heterogeneous, may show areas of low ADC
- THUS: diagnosis should preferentially be made by early-late T2
- Value for DWI: avoid false positive – exclude M+ in subcentimetric lesions seen on CT
Solid benign lesions

FNH and adenoma have a highly variable appearance on DWI/ADC
Exploit every possible morphologic feature
ADC-threshold: dependent on base signal on native images
Overlap with metastases of adenocarcinoma, but less signal on native DWI

Variable ADC and SI of lesions due to heterogeneity in histologic background:
Steatotic adenoma - FNH
Teleangiectatic / inflammatory adenoma....

If no signal on native b-values \(\rightarrow\) consider benign – don’t calculate ADC
ADC range: 0.0011 – 0.0015
Also check for morphologic clues
SOLID BENIGN LESIONS:
THE VARIABLE APPEARANCE OF ADENOMA

Steatotic adenoma → if b1000 is negative → don’t proceed with ADC, consider negative

Malignant lesions: metastases

Table 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Namimoto et al. [12]</th>
<th>Ake et al. [40]</th>
<th>Tsai et al. [50]</th>
<th>Elmoayed et al. [45]</th>
<th>Granot-Gilad et al. [46]</th>
<th>Poli et al. [57]</th>
</tr>
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<tbody>
<tr>
<td>No. of patients/lesions</td>
<td>50/50</td>
<td>129/74</td>
<td>92/92</td>
<td>102/14</td>
<td>64/17/4</td>
<td>53/11</td>
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<td>ADC max (mm²/s)</td>
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<td>1.83</td>
<td>1.24</td>
<td>1.25–1.31</td>
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<td>Metastases</td>
<td>1.15</td>
<td>1.06–1.11</td>
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<td>1.32</td>
<td>0.99</td>
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<td>HCCs</td>
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<td>Hemangiendotheliomas</td>
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<td>Cysts</td>
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<td>Adenocarcinoma: focal nodular hyperplasia</td>
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<td>Benign lesions</td>
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<td>Malignant lesions</td>
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<td>ADC cutoff for diagnosis of malignant liver</td>
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<td>1.58</td>
<td>1.50</td>
<td>1.51</td>
<td>Not applicable</td>
<td>1.61</td>
</tr>
</tbody>
</table>

* ADCs for b < 1000 mm²/s are given.
† ADCs for b > 1000 mm²/s are given.
‡ Lesions with ADCs below the proposed cutoff value are considered malignant, while those with ADCs above are considered benign.

B1000 Signal intensity and signal heterogeneity

Threshold UZ: ~ 0.00011

Correlate with native images
MALIGNANT LESIONS: METASTASES

M+ breast cancer

M+ colorectal → major additional value = detection of millimetric metastases = better staging
CAVE necrotic and mucinous metastases: lesion heterogeneity – false negative ADC

IMAGING OF CIRRHOSIS

**Screening**: early detection of HCC → curability

- Negative: follow-up
- Positive
- Staging
  - Transplantation
  - Surgery - RFA
  - Systemisch chemothrapie
  - Chemotherapy

**Supportive**

Anatomy
Cirrhosis
Complications
Cirrhosis: diffusion-weighted anatomy

Liver background in cirrhosis is most important pitfall

Fibrotic septa

Iron overload of liver

PATHOPHYSIOLOGY: CELLULAR CHANGES

Window of opportunity: early cellular changes
Exclusion of microcirculatory pollution
B-value > 300

Hypovascular HCC
Hypervascular pseudotumor

Cellular
Tumorperfusion
Cirrhosis image generation

Cirrhosis: signal generation

1. No ADC quantification :
   - Noise versus diffusion restriction

2. b600-SI optimal threshold
   - Cellular changes => malignant transformation
   - Exclude perfusion effects => pseudotumor

3. Improved conspicuity of small lesions
   - Early detection of HCC
   - Pretransplant staging?

4. Prediction of lesion progression
   - Timing of follow-up/intervention
   - Eligibility for transplantation

V. Vandecaveye et al, Eur radiol 2009
**Heterogeneity as a diagnostic marker?**

- Anatomical lesion size does not correspond with DWI lesion size

- The hepatocellular paradox → usually large HCC is not visible at DWI according to conventional standards
  → small lesions easily identified

- Tool for characterization: yes – only in combination with contrast-enhanced imaging

- Staging tool due to the improved detection of subcentimeter lesions

- Large lesions: often well differentiated HCC – DWI only detects regions with highest tumoral cell density
  → DWI lesion-in-lesion
Heterogeneity as a diagnostic marker

Well differentiated HCC

Detection and characterization

HCC
Staging

Low grade dysplastic nodule

HCC – fibrotic variant

Fatty degeneration

Always correlate DW-MRI to conventional MRI → characterization
Pitfalls

Nodular regeneration after portal vein thrombosis
Confluent fibrosis

Cholangiocarcinoma
Cholangiocarcinoma

- The major role of DWI is for lesion detection – characterization of malignancy and staging
- Currently unclear if the detection of cholangiocarcinoma can be improved on a background of PSC
- No specific DWI features that allow the pure differentiation from M+ or HCC ➔ + contrast-enhanced MRI

**Improved detection of small lesions - Cui XY, World J Gastroenterol 2010**

Cholangiocarcinoma

Routine MRI-cholangiography (1.5 T) in patient with jaundice and right hypochondric pain

- Free margin to left lobe (Klatskin IIIa)
- Right extended hemihepatectomie planned
Hilar and intrahepatic tumor infiltration
Peritoneal metastases
Inoperable

Cholangiocarcinoma

Extrahepatic imaging

IMAGING PANCREATIC CANCER: A CONTROVERSY?

ABDOMINOPELVIC IMAGING / RECURRENCE IMAGING
PANCREATIC DWI: ANATOMY

- Highly variable depending on the presence of chronic pancreatitis, lipomatosis, etc.

IMAGING PANCREATIC CANCER: A CONTROVERSY?

• High b-value DWI/ADC shows high accuracy for pancreatic adenocarcinoma

• Ichikawa T, Abdominal Imaging 2007

• Kartalis N, Eur Radiol 2009

• Pancreatic adenocarcinoma shows hyperintense signal on high b-value due to diffusion restriction

• CAVE: variable contrast with pancreatic carcinoma

• Anatomical imaging

Exocrine pancreas

Pancreatic adenocarcinoma

Less restriction

More restriction

Pancreatic Adenocarcinoma:

Variability of Diffusion-weighted MR Imaging Findings

Yoshinori Tsuchiya, MD, PhD
Koji Takahashi, MD
Kiyoko Harada, MD, PhD

Yoshikazu Takeuchi, MD
Yuji Ikuhara, MD
Alfredo Tejera, MD
Mayo Akagi, MD, PhD
PANCREATIC DWI: INDICATIONS AND INTERPRETATION

** Currently no clear agreement

UZ Leuven: indications and interpretation

** Detection of neuro-endocrine tumors
  b1000 + anatomy

** Detection of carcinoma in chronic pancreatitis
  b1000 + ADC + anatomy

** Facilitate detection of small adenocarcinoma in dilated Wirsung duct
  small sized lesions: b1000+ anatomy

** Malignant transformation of IPMN
  solid component in cyst? : b1000+anatomy

NEURO-ENDOCRINE TUMOR

Diagnosis of pancreatic neuro-endocrine tumor
NEURO-ENDOCRINE TUMOR

Patient with repetitive hypoglycemic attacks

Improved lesions conspicuity -> improved lesion detection

CARCINOMA IN CHRONIC PANCREATITIS
RESTAGING POST-TREATMENT

**Surrounding tissue:**
- Inflammation-fibrosis
- b1000 –
- ADC often increased
- Variable in late phase

**Tumoral recurrence:**
- Solid hypercellular
- b1000 +
- ADC often decreased

**Viable rim**
- Necrotic center

TUMOR HETEROGENEITY

Koh D, Collins D, AJR 2007
**POST-TREATMENT IMAGING**

Patient with elevation of CEA after total mesorectal excision and neo-adjuvant (chemo)radiotherapy

Fibrosis/inflammation versus tumour recurrence?

ADC=0.00105

Pelvic recurrence confirmed by surgical biopsy

**RESTAGING POST-TREATMENT**

Prior neo-adjuvant chemoradiation and surgery for rectal cancer

CT shows intrapelvic mass – normal tumormarker CEA

DWI as an additional imaging technique

Screen for restrictive lesions

Signal suppression in inflammation

Application chemoradiation>surgery
Patient with prior low anterior resection after neo-adjuvant chemoradiation for rectal cancer. Clinically increasing tumor marker, Increased FDG-uptake at the site of resection.

Pitfall: abscess !!!!! Major cause of false positive
Correlate to conventional imaging
Area of liquefaction -> restricted diffusion -> likely abscess
   -> facilitated diffusion -> likely (tumoral) necrosis
TAKE HOME MESSAGES

Investing into knowledge and training

Investing into communication

What we say to dogs
Okay, Ginger! I've had it!
You stay out of the garbage!
Understand Ginger? Stay out of the garbage, or else?

What we say to clinicians
b-1000 hyperintensity indicates tumor. The ADC below 25% confirms relapse.

What they hear

What they hear