Abdominal MRI in 2012

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technical developments, standardization of sequences and use of specific contrast agents

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It all started with an idea...

Raymond Damadian MRI prototype 1977

Tumor Detection by Nuclear Magnetic Resonance, Science, March 1971

Fonar 1978 - First MR scanner

Indomitable - first MRI image

Fonar QED 80 - First commercial MR scanner

1978

2012
Abdominal MR imaging

- Expectations in 2012
  - Pathology detection
  - Pathology characterization
  - Management decision
  - Detection of complications

CT & MR

CT

MR

Too many choices...

MPRAGE
- T1 in/out of phase
- 3D SS T1
- spectral fat suppression

FLAIR
- T2
- Spoiled GE T1
- Radial K-space reading

T1
- T1 in/out of phase
- T1
- T1 in/out of phase

T2
- TurboFLASH
- water excitation

FIESTA
- HASTE
- 3D SS T1
- BLADE

T1
- T1 in/out of phase
- T1
- T1 in/out of phase

Too many choices...

Keyhole imaging
MR scan protocol

- Understandable to technician & radiologist
  - start always with a limited number of all-round protocols
  - limit specific protocols for specific situations
- Executable within reasonable timeframe
  - <=25 minutes
MR scan protocol

- Understandable to technician & radiologist
  - start always with a limited number of all-round protocols
  - limit specific protocols for specific situations

- Executable within reasonable timeframe
  - <=25 minutes

- Ensure technical success in highest number of patients!
  - motion, motion, motion....

What are our options?
mix of old and new technologies

- Improve image quality
- Improve lesion characterisation

- Anatomy
- Tissue characterization

Improve image quality

- Anatomy
- Tissue characterization

Reduce motion
Improve SNR

Anatomy
Tissue characterization

It was not invisible, but unnoticed dear Watson*

A case of Identity

* Sherlock Holmes, A case of Identity
Resolution is not everything...

- 0.4 x 0.6 x 0.4 mm

Motion

- MR is increasingly popular
  - sensitivity & specificity for detecting lesions
  - expanding indications
  - expanding installed base of MR scanners

- Referred population
  - intensive care
  - sicker & less or no cooperating patients

- Raising expectations

Motion-reducing techniques

- requiring patient cooperation
- Anatomic reference triggering
- Advanced Sequence-based
- Reducing acquisition time

Breath-hold imaging

- respiratory (diaphragmatic) gating
- Single shot sequences
- Radial K-space sampling
- Parallel imaging

Motion

- Breath-hold

- Anatomic reference triggering
- Single shot sequences

Single shot imaging


T2 echo train SE

Single shot imaging
• Single Shot sequences

- T2 echo train SE
- T1 magnetization-prepared RAGE
- HASTE, SSFSE
- T1/T2 balanced GE sequences

Motion

- Single shot imaging
- T1 magnetization-prepared RAGE
- Turbo FLASH, MPRAGE

Motion

- T2 echo train SE

Free-breathing

HASTE T2-weighted image

Motion

- T2 echo train SE

Breath-hold

HASTE T2-weighted image

Motion

- T1 magnetization-prepared rapid acquisition GE

2D GRE T1-weighted image

Motion

- T1/T2 balanced GE

TrueFISP T2-weighted image
Motion

- T1/T2 balanced GE
- TrueFISP T2-weighted image
- Bright vessels - flowing blood
- Fetal imaging

Motion

- Radial K-space sampling
- K-space raw data
- Contrast detail
Motion

- Radial K-space sampling

K-space raw data

- BLADE, PROPELLER
- T1-weighing
- T2-weighing

General characteristics
- average 2 minutes acquisition time
- free breathing!
  - critically-ill patients
  - children
  - cognitively impaired
- fat-suppression possible

Continuous acquisition of low resolution images during motion measurement & correction of motion upgrading of low to high resolution images

Improving image quality

- Improving SNR
- High-field imaging (3T)
- Parallel imaging
- High-relaxivity contrast agents

Same spatial resolution in shorter examination time
Better spatial resolution in same examination time
Better temporal resolution
3T imaging - Facts & Myths

- Field strength vs SNR

1.5 T + 1.5 T = 3 T

SNR

SNR

2x SNR

SNR-determining parameters

- Field strength
- Sampling Time
- Sequence-specific parameters

T1 relaxation time
Receiver bandwidth
SAR

3T imaging - SNR

- T1 relaxation increases with field strength

Field strength (T)

T1 (msec)

Bottomley PA et al
A review of normal tissue hydrogen NMR relaxation times and relaxation mechanisms from 1–100 MHz: dependence on tissue type, NMR frequency, temperature, species, excision, and age
Med Phys 1984; 11:425–448

SNR change is organ-dependent

3T imaging - SNR

- Specific absorption rate (SAR)

1.5 T

SAR x 4

3 T

sensation of warmth
TR
slice number
flip angle
3T imaging - SNR

- Susceptibility artifacts increases!

HASTE T2 - 1.5 T HASTE T2 - 3 T

3T imaging - SNR

- Susceptibility artifacts increases!

HASTE T2 - 1.5 T HASTE T2 - 3 T

TrueFISP - 3T

- Standing waves

RF wavelength is similar to the diameter of the torso
23 cm at 3.0 T vs 47 cm at 1.5 T

3T - SNR

- Standing waves

RF wavelength is similar to the diameter of the torso
23 cm at 3.0 T vs 47 cm at 1.5 T

Water
Parallel Imaging

- Multiple receive coil elements
  - SENSE: sensitivity encoding
  - ASSET: array spatial sensitivity encoding technique
  - IPAT: integrated parallel acquisition technique
  - GRAPPA: generalized autocalibrating partially parallel acquisition
  - SMASH: simultaneous acquisition of spatial harmonics
- Shorter scan times with little influence on image quality
  - Reduction in scan time: up to 6-fold
  - Higher resolution within same scan time
  - Same resolution in shorter (breath-hold) time

Parallel Imaging

- Reduce scan time
  - 24 seconds vs. 12 seconds
  - Shorter scan acquisition increases technical success of examination

Parallel Imaging

- Combined 3T & parallel imaging
  - 256 matrix vs. 512 matrix
  - Better T2-signal & higher matrix

Tissue Characterization

- Fat, water, iron
- Diffusion-weighted imaging
- Contrast-enhancement
- Perfusion

Tissue Characterization

- Fat in Liver imaging
  - T1-weighted image in phase
  - T1-weighted image out of phase
  - Liver steatosis

Tissue Characterization

- Fat, water, iron
- Diffusion-weighted imaging
- Contrast-enhancement
- Perfusion
Tissue characterization

- Fat content quantification using Dixon technique

Transverse breath-hold multiecho MR imaging acquisition

O'Regan DP et al. Liver fat content and T2*: simultaneous measurement by using breath-hold multiecho MR imaging at 3.0 T. Radiology. 2008 May;247(2):550-7

Tissue characterization

- Diffusion-weighted imaging

Brownian motion

looking for restricted diffusion indicating change in cellularity

Tissue characterization

- Diffusion-weighted imaging

b: 50

b: 600

b: 1000

Tissue characterization

- Diffusion can be restricted in
  - cytotoxic edema (infection)
  - lesion of high cellularity (metastases)
  - high viscosity (abcess)
  - excitotoxic damage (glutamate)

Detection & differentiation of
- liver metastases
- HCC
- post-treatment inflammation & fibrosis vs tumor relapse
**Tissue characterization**

- MR elastography
  - normal liver
  - cirrhotic liver

- MR-E acquisition at 60 Hz indicating longer wavelength in cirrhotic liver

**Perfusion**

- Morphology meets vascularity

**MR contrast agents**

- Gadolinium chelates
  - T1-shortening
  - Blood

*William Shakespeare, Macbeth*

**Anatomy of a scan protocol**

- Determine indication
  - Detection of pathology
  - Pre-operative planning
  - Follow-up of existing disease

- Optimize scan protocol
  - Scan range
  - Number of phases
  - Contrast medium and injection protocol

- Choice of contrast medium type
Physiological principles

- Pharmacokinetics of CM delivery
  - X-ray CM: extracellular fluid marker
  - Rapid distribution between vascular and interstitial compartments
- Complex early distribution - redistribution
- Vascular vs Parenchymal enhancement
  - Visualization of arteries and hypervascular lesions
  - Evaluation of liver parenchyma and hypovascular lesions

Phases of enhancement

<table>
<thead>
<tr>
<th>Phase</th>
<th>Time</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>15 s</td>
<td>Hepatic artery</td>
</tr>
<tr>
<td>II</td>
<td>30 s</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>60 s</td>
<td>Portal veins</td>
</tr>
</tbody>
</table>
Influence of Speed of injection of Contrast Medium

- 5 ml/s of CM
- 3 ml/s of CM
- 1 ml/s of CM


Key contrast phases

- Traditional dynamic phases
  - pre-contrast
  - Late hepatic arterial phase
  - portal venous phase
  - Late venous enhancement
- Transitional phase
  - extracellular compartment to hepatocellular compartment
- Hepatobiliary phase
  - variable onset & peak of enhancement!
  - depends on agent & liver status

Classification of contrast agents

- Extra-cellular agents
- Combined extra-cellular & hepatobiliary agents
- Blood pool agents

Extra-cellular agents

- Distribution
  - blood
  - interstitium
  - lymphatics
  - do not enter cells
  - Cleared by kidneys
  - Assess vascularity
- Gd-DTPA (Magnevist)
- Gd-DOTA (Dotarem)
- Gadoteridol (Prohance)
- Gd-DO3A-butrol (Gadovist)
- Gadoxetate (Primovist)
- Gadebenate (Multihance)

Extra-cellular contrast

- Typical & non-specific contrast enhancement patterns
- Hemangioma
- Telangiectatic FNH
- Gadoxetate (Primovist)
- Gadebenate (Multihance)

Extra-cellular & hepatobiliary agents

- Distribution
  - blood, interstitium, lymphatics
- Hepatobiliary uptake & excretion
  - enter hepatocytes via transporters
  - excreted by hepatocytes into bile via transporters
- Clearance
  - kidneys & liver
  - Assess hepatocyte ‘function’
  - transported density
  - vascularity
**Hepatobiliary contrast agents**

- Detection of bile ducts in lesions

![Image of liver with bile ducts](image1)

Partial bile excretion - still enhancement on delayed imaging

*Focal nodular hyperplasia with Gadobenate dimeglumine*

**MR contrast agents**

- When to scan?

<table>
<thead>
<tr>
<th>Phase</th>
<th>Delay after CM injection</th>
<th>Relative timing</th>
<th>Indication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-enhanced</td>
<td>0 s</td>
<td>N/A</td>
<td>Steatoic, pyogenic cholangitis</td>
</tr>
<tr>
<td>Early arterial phase</td>
<td>20 s</td>
<td>$T_{rel}$ + 8 s</td>
<td>Arterial mapping</td>
</tr>
<tr>
<td>Late arterial phase</td>
<td>30 s</td>
<td>$T_{rel}$ + 16 s</td>
<td>Hypervascular lesions</td>
</tr>
<tr>
<td>Portal venous phase</td>
<td>65 s</td>
<td>$T_{rel}$ + 50 s</td>
<td>Hypervascular lesions</td>
</tr>
<tr>
<td>Late venous phase</td>
<td>3 min</td>
<td></td>
<td>Well-differentiated HCC, retention of contrast in hemangiomas</td>
</tr>
<tr>
<td>Excretory phase</td>
<td>6-10 min</td>
<td></td>
<td>Fibrous tumors, cholangiocarcinoma</td>
</tr>
</tbody>
</table>

**MR contrast agents**

- How many phases?

<table>
<thead>
<tr>
<th>Patient</th>
<th>UN</th>
<th>EAP</th>
<th>LAP</th>
<th>PVP</th>
<th>EP</th>
</tr>
</thead>
<tbody>
<tr>
<td>No liver disease</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-specific history</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>No liver disease</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Screening hypervascular lesion</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Liver disease</td>
<td>?</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>

**New developments**

- Increased Gadolinium concentration
  - Gadobutrol (Gadovist, Bayer Shering)
  - double Gd-concentration 1.0 M compared to conventional contrast agents (0.5 M)

**New agents**

- Blood pool agents: Gadofosveset-trisodium (Vasovist)
  - Contrast product binds to Albumine

**New agents**

- Blood pool application in body MR is limited

**New Horizons**

- Blood pool agents

<table>
<thead>
<tr>
<th>Relaxivity in Human Plasma</th>
<th>Field Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.5 T</td>
</tr>
<tr>
<td>Gd-DTPA</td>
<td>4.10</td>
</tr>
<tr>
<td>Vasovist (R)</td>
<td>19-28</td>
</tr>
<tr>
<td>Relative increase</td>
<td>5-7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relaxivity in Human Plasma</th>
<th>Field Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 T</td>
</tr>
<tr>
<td>Gd-DTPA</td>
<td>3.70</td>
</tr>
<tr>
<td>Vasovist (R)</td>
<td>10-19</td>
</tr>
<tr>
<td>Relative increase</td>
<td>3-5</td>
</tr>
</tbody>
</table>

**What about NSF?**

<table>
<thead>
<tr>
<th>Contrast material</th>
<th>Estimated GFR (ml/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&gt;60</td>
</tr>
<tr>
<td></td>
<td>45-59</td>
</tr>
<tr>
<td></td>
<td>30-44</td>
</tr>
<tr>
<td></td>
<td>15-29</td>
</tr>
<tr>
<td></td>
<td>&lt;15 or dialysis</td>
</tr>
<tr>
<td>Iodinated Safe</td>
<td>Small risk</td>
</tr>
<tr>
<td></td>
<td>Avoid</td>
</tr>
<tr>
<td></td>
<td>Preferred*</td>
</tr>
<tr>
<td></td>
<td>OK if dialysis</td>
</tr>
<tr>
<td>Gadolinium-based</td>
<td>Safe</td>
</tr>
<tr>
<td></td>
<td>Minimal risk</td>
</tr>
<tr>
<td></td>
<td>Preferred</td>
</tr>
<tr>
<td></td>
<td>Avoid</td>
</tr>
<tr>
<td></td>
<td>contra-indicated</td>
</tr>
</tbody>
</table>

* requiring hydration and other measures


**What the future holds...**

- Integrative imaging
  - MR - CT - PET - ...

- Molecular imaging
  - Quantification of biomarkers

Detection, identification & follow-up of lesions on morphological & functional level

3T
But beware...

- Imaging of biomarkers
  - Must be technically mature
  - Available outside specialized centers
  - Comfortable & safe for patient
  - Standardization

VALIDATION

Final Thoughts

MR is continuously evolving

Complex technology can be overwhelming

3T is not always easier or better
Everything should be made as simple as possible, but not simpler*  

Emerging applications may change our way of work

Technology can only be successful when the patients benefits from the results

Thank you for your attention!