Advanced MRI in the Clinic: MR Spectroscopy

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Declaration of Financial Interests or Relationships

I have no financial interests or relationships to disclose with regard to the subject matter of this presentation.

MR Spectroscopy (MRS)

• MR spectroscopy (MRS) is a rapidly expanding clinical technique to quantify metabolites in vivo.
• This metabolic information may enable better diagnoses, personalized treatments, and rapid assessment of treatment response.
• After this talk, participants will know what these squiggly lines are and how to implement them in the clinic.
**Larmor equation**

\[ \omega = \gamma B \]

Magnetic information encoded in frequency (\( ^{1}H \), etc.)

**Extrinsic effects on magnetic field**
- \( B_0 \)
- Magnetic field gradients
- Magnetic field inhomogeneity

**Intrinsic effects on magnetic field**
- Chemical shift
- \( J \)-coupling

**Chemical shift**

- \( s \)-shielding constant

**Scalar spin-spin interaction**

Interaction between spins mediated through chemical bonds

**Slide courtesy of Ivan Tkáč.**

**Molecules of Interest**

**Primary peaks:**
- Total NAA (2.0 ppm)
- \( N \)-acetylaspartate and \( N \)-acetylaspartylglutamate
- Neuronal marker
- Total Cr (3.0 ppm)
- Creatine and phosphocreatine
- Energy buffer
- Total Chz (3.2 ppm)
- Choline, glycerophosphorylcholine and phosphorylcholine
- Membrane turnover

**Other peaks:**
- Glx (glutamine, glutamate)
- \( \gamma \)-Aminobutyric acid
- Lactate
- Lipids
- Myo- and scyllo-inositol
- Citrate
- (D)-2-hydroxyglutarate (2HG)
- Taurine
- Glucose
- Ethanol
- Mannitol
- Acetate and succinate
Clinical Uses of MRS

- MRS is indicated for a variety of neurological conditions (right) and additionally under investigation in other body sites (breast, prostate, liver, etc.).
- Common (and potentially reimbursed) uses include:
  - Primary diagnosis of brain lesions.
  - Distinguishing recurrent brain tumor from radiation necrosis.
  - Diagnosis of inborn errors of metabolism affecting the CNS


Reimbursement

- MRS has an associated CPT code: 76390.
- Reimbursement for this code is inconsistent.
- The ACR is working for consistent reimbursement.

https://www.evicore.com/referenceguidelines/06_2018-head.pdf

MRS System Requirements

Hardware:
- Homogeneous magnetic field
- Linewidth desired < 0.1 ppm
- 6 Hz @ 1.5 T; 12 Hz @ 3 T
- Field strength and bore size are not very important.
- Standard head coil (e.g. 8-channel brain array)
Single Voxel Spectroscopy (SVS)

- Most common technique
- Simple to acquire and interpret
- Excellent SNR efficiency
- Single, localized voxel allows for excellent shimming and, therefore, high-quality spectra

Clinical SVS Sequences

- ISIS
- STEAM
- PRESS
- LASER/semi-LASER

Multi-Voxel Spectroscopy (MVS)

- A larger total coverage area takes the guesswork out of SVS voxel placement.
- Smaller individual voxels are possible, which leads to higher spatial resolution, but lower SNR and potential spectral contamination from adjacent voxels.
- Acquisition times are usually long.
- Difficulties obtaining a good shim over the entire region result in reduced quality.
- MVS sequences are usually just SVS sequences (e.g. PRESS) with phase encoding.
Choice of TE

- Longer TE leads to nicer spectra and easier interpretation, but fewer metabolites are visualized.
- Short TE is usually recommended for evaluating metabolic and neurodegenerative disorders and intermediate TE is usually recommended for lesion assessment.
- Changing the TE (or TR) can dramatically change the appearance/invert certain metabolites.

Clinical Water Suppression

- Water signal is approximately 10,000 times more intense than metabolite signals.
- Clinical water suppression uses chemically-selective saturation (i.e., Fat Sat tuned to water).
- CHESS is most common.
- VAPOR is better.

MRS Processing

- Vendor software usually only calculates peak heights/integrals and peak ratios.
- More advanced fitting software is available (e.g., LCModel, TARQUIN), but these are not FDA approved.
**MRS Artifacts**

- Artifacts in MRS appear very different from artifacts in MRI and are often less conspicuous.

**Contrast and MRS**

- In clinical practice, the effect of gadolinium-based contrast agents (GBCAs) on non-quantitative MRS is usually insignificant, EXCEPT:
  - Ionic GBCAs can decrease choline signal.

**MRS QA**

- AAPM Report 100 (2010) details recommended MRS acceptance testing using a phantom.
- Phantom-based MRS QA alone is insufficient since the simple phantom poorly emulates both the biochemical milieu and electromagnetic environment of the human brain.
  - The EBMIM MRS Consensus Group (2014) recommends in vivo MRS QC.
  - Performing MRS QC in vivo should produce more accurate and relevant results.
  - Our institution is transitioning to real-time patient MRS QC for quality verification and longitudinal monitoring of scanner performance.
Non-Proton MRS

- Non-proton MRS is still in clinical trials with $^{13}$C and $^{31}$P closest to routine clinical use.
- $^{13}$C and $^{31}$P are primarily used for metabolic imaging.
- There is now a clinical hyperpolarizer available for $^{13}$C that boosts the signal by 10,000x.

<table>
<thead>
<tr>
<th>Nucleus</th>
<th>Natural Abundance (%)</th>
<th>Zeeman magnetic ratio (MHz/µT)</th>
<th>Hyperpolarized Sensitivity</th>
</tr>
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<tbody>
<tr>
<td>$^{13}$C</td>
<td>0.01</td>
<td>16.75</td>
<td>1.15</td>
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<tr>
<td>$^{1}$H</td>
<td>100.00</td>
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<td>$^{15}$N</td>
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<tr>
<td>$^{13}$P</td>
<td>100.00</td>
<td>17.23</td>
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<td>$^{19}$F</td>
<td>95.00</td>
<td>4.99</td>
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In conclusion, MR spectroscopy has a variety of clinical applications and is relatively simple to implement.

Thank you!