FUNCTIONAL IMAGING: MAGNETIC RESONANCE SPECTROSCOPY

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Introduction

\[ \omega = \gamma \times B_0 \]

Larmor Frequency
**Prostate Metabolism**

**Role of Citrate**
- Active accumulation and secretion by the normal prostate
- Very high concentration in prostatic fluid (500 times higher than in plasma)
  - maintenance of acidity (pH = 6.5)
  - chelation of cations
  - energy provision
  - capacitation of sperm

**Role of Citrate**
- Decreased citrate in neoplastic prostate
  - oxidized in Krebs-cycle to fulfill neoplastic energy requirements
  - gradual replacement of (citrate-containing) ductal compartment by increasing volume of citrate-poor neoplastic cells (especially in Gleason patterns 4 and 5)
Choline

- Involved in membrane synthesis and degradation
- Higher membrane turnover in cancers
- [total choline] is composed of several compounds
  - e.g. phosphocholine, glycerophosphocholine, free choline
  - in vivo spectroscopy cannot resolve individual components

Creatine

- Creatine concentration usually low in the prostate
- Concentration in normal tissue ≈ concentration in cancer tissue
- Insignificant for diagnosis, but difficult to resolve from choline at 1.5T

Polyamines

- Variable multiplet at 3.1 ppm
  - at 1.5T: impossible to resolve from choline and creatine
  - at 3T: occasionally better resolved
- Play a role in regulation of cell proliferation and differentiation
- Reduced or absent in cancer
MR Spectroscopy
Image Acquisition

Image acquisition
Spectroscopic sequence

- 3D-CSI MRS
  - 3-dimensional chemical shift imaging magnetic resonance spectroscopy
  - full coverage of prostate gland
  - voxel size < 0.5 cc

Image acquisition

- VOI (volume of interest)
- Saturation bands
Shimming

- Larmor Frequency of protons
  - in homogeneous magnetic field (e.g. 1.5T)
    \[ \omega = \gamma B_0 \text{ number} \]
  - in inhomogeneous magnetic field (e.g. \[(1.5 - \rho, 1.5 + \rho)\]T)
    \[ \Delta \omega = \gamma \Delta B_0 = \text{range}! \]

Shimming

- Automatic shimming (provided by vendor): up to line width of 30 Hz
- Manual shimming: further fine-tuning
  - 1.5 T: up to 15-20 Hz
  - 3.0 T: up to 20-25 Hz

MR Spectroscopy
Postprocessing
Postprocessing
FID (free induction decay)

Postprocessing
Water reference processing

Postprocessing
Zero filling

Postprocessing
Filtering (Hanning)

Postprocessing
Fourier transformation

Postprocessing
Phase correction
Postprocessing

Frequency correction

- Removal of (residual) water components in water reference processing
- Optionally Hanning filtering of spatial dimensions in combination with elliptical or weighted k-space sampling
- Zero-filling in spatial dimensions to the nearest power of 2
- Fourier transformation in time and three spatial domains
- Optional baseline correction using non-peak regions of the spectrum
- Automatic frequency alignment using prior knowledge of resonance positions and peak widths, to compensate frequency shifts due to $B_0$ inhomogeneities
- Automatic phase correction, with manual fine-tuning if needed

Postprocessing

Baseline correction

Postprocessing

Curve fitting

Postprocessing

Input

Postprocessing

Output

Postprocessing

Standardized protocol
Postprocessing
Voxel evaluation

Normal prostate voxel

1H-spectrum

Postprocessing
Whole prostate evaluation

3D evaluation of prostate

MR Spectroscopy
Spectral evaluation

Mathematical Curve Fitting

Spectral evaluation
Quantitative approach

Citrate map

Choline+Creatine map

Spectral evaluation
Quantitative approach

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Quantitative approach

Scheenen et al, Invest Radiol 2011;46:25-33

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Chol + Creat
Citrate

Spectrum
Index

2 SD = possible cancer
3 SD = definite cancer
Spectral evaluation
Quantitative approach

Score 1
Normal

Score 2
Probably benign

Score 3
Probably malignant

Score 4
Definitely malignant

Scheenen et al, Invest Radiol 2011;46:25-33

3 SD = possible cancer

4 SD = definite cancer

Citrate peak at least two times higher than choline/creatine peak

Citrate peak smaller than two times or equal to choline/creatine peak

Choline/creatine peak smaller than two times but higher than citrate peak

Choline/creatine peak at least two times higher than citrate peak (if present)

Eur J Radiol 2010;73:352

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Spectral evaluation
Synopsis
• Quantitative analysis
  – CC/C < 2 SD above mean CC/C = normal
  – CC/C > 2 SD above mean CC/C = tumor
• Qualitative analysis
  – Citr > Ch = normal
  – Ch > Citr = tumor
  … in at least 3 adjacent voxels
  … at 1.5T

Be careful…
• Fluid in seminal vesicles and ejaculatory ducts contains glycerophosphocholine → “false positive” choline peaks!

Be careful…
• Noise → “false positive” choline and/or citrate peaks!
Be careful…

- Inadequate fat suppression  
  → “false positive” citrate peaks!

Take home messages

- Spectroscopy = imaging of molecule-specific precessing frequency shifts (“chemical shift imaging”)
- Relevant metabolites
  - Citrate: marker of normal prostate
  - Choline: marker of prostate cancer
  - Creatine: unimportant
  - Polyamines: reduced/absent in cancer

Take home messages

- Requirements for optimal spectroscopy
  - 3D CSI MRS sequence
  - Optimal position of VOI and sat bands
  - Shimming
  - Postprocessing protocol
- Data analysis
  - Quantitative
  - Qualitative