Improved Spatial Localization in 3D MRSI with a Sequence Combining PSF-Choice, EPSI and a Resolution Enhancement Algorithm

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Goals

• **Improve spatial localization in MR spectroscopic imaging (MRSI) by eliminating truncation (or ringing) artifact.**

• **Increase speed by employing an echo-planar approach to encode one spatial dimension.**

• **Investigate the use in MRSI of a resolution enhancement method (super-resolution).**
Enhancements to Standard MR Spectroscopic Imaging (MRSI)

- Implement PSF-Choice\(^1\) in 2 dimensions
- Implement Echo-Planar Spectroscopy\(^2\) in 3rd dimension.
- Acquire multiple low-resolution data sets and apply a resolution-enhancement algorithm (super-resolution\(^3\)).

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What is PSF-Choice?
A method that **improves** the point-spread-function (PSF) and **eliminates** ringing artifact.

1. PSF of standard phase encoding
2. PSF with PSF-Choice

Results in intra-voxel spectral contamination

FWHM (resolution) of both PSFs
Support of PSF 2
Support of PSF 1

How is PSF-Choice implemented?

1. Replace the standard 90° RF excitation pulse with a train of RF sub-pulses.
2. Change amplitudes of the sub-pulses on each excitation according to a weighting scheme that determines the resultant PSF.
Example: 4x4 PSF-Choice Encoding

Each RF sub-pulse samples a different location in excitation k-space

The standard RF excitation pulse is replaced with a train of 4 sub-pulses in our scheme. Amplitudes of the sub-pulses are changed on each excitation according to Gaussian k-space weighting.
Two-dimensional PSF-Choice Encoding

With each excitation a new set of 4 points in excitation k-space is sampled.
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With each excitation a new set of 4 points in excitation k-space is sampled.
2D PSF-Choice Reconstruction

When combining the results from all excitations, the net effect is excitation of a Gaussian-shaped ‘virtual profile’ in the PSF-encoding directions, X and Y.
2D PSF-Choice Reconstruction

By applying a linear phase ramp to data from the different excitations, the virtual profile can be shifted within the field-of-view.
2D PSF-Choice Reconstruction

For a \( N \times N \) PSF-Choice encoding, spectra from \( N \times N \) different locations can be reconstructed. The effective PSF is determined by the shape of the virtual profile - e.g., a Gaussian PSF in our case.
PSF-Choice Encoding vs Fourier Encoding: Results in Phantom

- GE 3T Signa System (15M4).
- 3D MRSI acquisitions:
  - PSF-Choice encoding in $x$ and $y$
  - EPSI in $z$.
- GE Quadrature head coil.
- GE MRS phantom.
Improved spatial localization in 3D MRSI with a sequence combining PSF-Choice, EPSI and a resolution enhancement algorithm.

PSF-Choice Encoding vs Fourier Encoding

8 x 8 images of H$_2$O peak.  Selected volume is smaller than voxel size.
Mapping the Point-Spread-Function

Excite a small volume and acquire multiple image sets with 1/4-voxel shifts in each direction (4x4 shifts = 16 acquisitions)
Improved spatial localization in 3D MRSI with a sequence combining PSF-Choice, EPSI and a resolution enhancement algorithm

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Experimentally Mapping the Point-Spread-Function

Data from the 16 image sets were interleaved (shifts of 1/4 pixel in two directions). Result forms high-density image of ‘point’ - PSF of the imaging method.
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Echo-Planar Spectroscopic Imaging (EPSI)

A method that encodes 1 dimension in a single shot and increases speed significantly

Prepare, Excite and Refocus MR Spins

Gradient

Sample

PRESS compared to EPSI with PSF-Choice

**H₂O images**

**Acquisition Matrix**

**PRESS:**
32x16x512 - 1 average

**EPSI & PSF-Choice:**
32x16x512 - 32 averages

**FOV = 24x12 cm**

**TE/TR = 85/1000 msec**

**Total acquisition time:**
32x16 shots X 1 sec = 8 minutes 32 seconds (for both methods)

Press vs EPSI with PSF-Choice

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<thead>
<tr>
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<th>Standard PRESS</th>
<th>EPSI &amp; PSF-Choice</th>
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<tr>
<td><strong>Acquisition</strong></td>
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<td>Matrix</td>
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<tr>
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- Implement PSF-Choice\textsuperscript{1} in 2 dimensions
- Implement Echo-Planar Spectroscopy\textsuperscript{2} in 3rd dimension.

Acquire multiple low-resolution data sets and apply a resolution-enhancement algorithm (super-resolution\textsuperscript{3}).

Resolution Enhancement (or ‘super resolution’)

- Combine multiple low-resolution datasets with sub-pixel shifts to enhance resolution.
- PSF-Choice is suitable for resolution enhancement approaches because the PSF contains higher spatial frequency information.
- Standard Fourier encoded data contains no additional spatial frequency information.

Irani and Peleg. 10th Int Conf Pattern Recogn 1990; 2:115-120.
Resolution Enhancement: Algorithm

**Initialize:**
Set high-resolution estimate, \( F_e \), equal to the interleaved low-resolution datasets.

**Low resolution estimate, \( F \), set equal to last high resolution estimate convolved with the assumed PSF.**

**Compute difference, \( F_d \), between the measured low-resolution data and the low-resolution estimate.**

**Update high resolution estimate by adding the error, \( F_d \), convolved with a back-projection kernal, \( BP \).**

\[
F_0 = F_l
\]

\[
F = F_e \ast \text{PSF}
\]

\[
F_d = F_l - F
\]

\[
F_{e_{n+1}} = F_e_n + F_d \ast BP
\]

\[n = n + 1\]

**Done?**

\[\text{Yes, exit.}\]
Resolution Enhancement: Phantom Results

**Standard Phase Encoded MRSI datasets: H$_2$O images.**

1 Acquisition  
4 Acquisitions  
Enhanced

**PSF-Choice Encoded MRSI datasets: H$_2$O images.**

1 Acquisition  
4 Acquisitions  
Enhanced

Data was acquired using GE ‘resolution’ phantom. Four acquisitions with 1/2 pixel shifts in x and y.
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Resolution Enhancement: With noisy MRSI data

**FOV = 80mm³**
**Press voxel = cube; 20mm³**

**Acquisition matrix = 8x8x8**

**Four acquisitions:**
Half pixel shifts in two directions, reconstructed and combined using super-resolution algorithm.

**Citrate image: 2.32 to 2.56 ppm.**

Data acquired using ‘prostate’ phantom (choline, creatine and citrate solution).

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**PSF-Choice Encoding (Citrate Image)**

Raw Data

With Enhancement

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**Standard Phase Encoding (Citrate Image)**

Raw Data

With Enhancement
Summary and Conclusions

• **PSF-Choice encoding** gives spectroscopic images free of truncation artifact.

• **Use of EPSI** to encode one direction reduces acquisition time: e.g., 24x12x8 matrix, 4 averages in 6min 24sec (TR=1sec).

• By repeating low resolution acquisitions with 1/2 pixel shifts in the PSF-Choice directions (in place of 4 simple averages), resolution enhancement methods can be applied.

• **Low-resolution, averaged data** is still available if high-resolution result is too noisy.
Acknowledgements

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