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]).**

1. Panych et al. Magn Reson Med 2005; 54(1):159-68.
2. Posse et al. Magn Reson Med 1995; 33(1):34-40.
3. Irani and Peleg. 10th Int Conf Pattern Recogn 1990; 2:115-120.

Enhancements to Standard MR Spectroscopic Imaging (MRSI)

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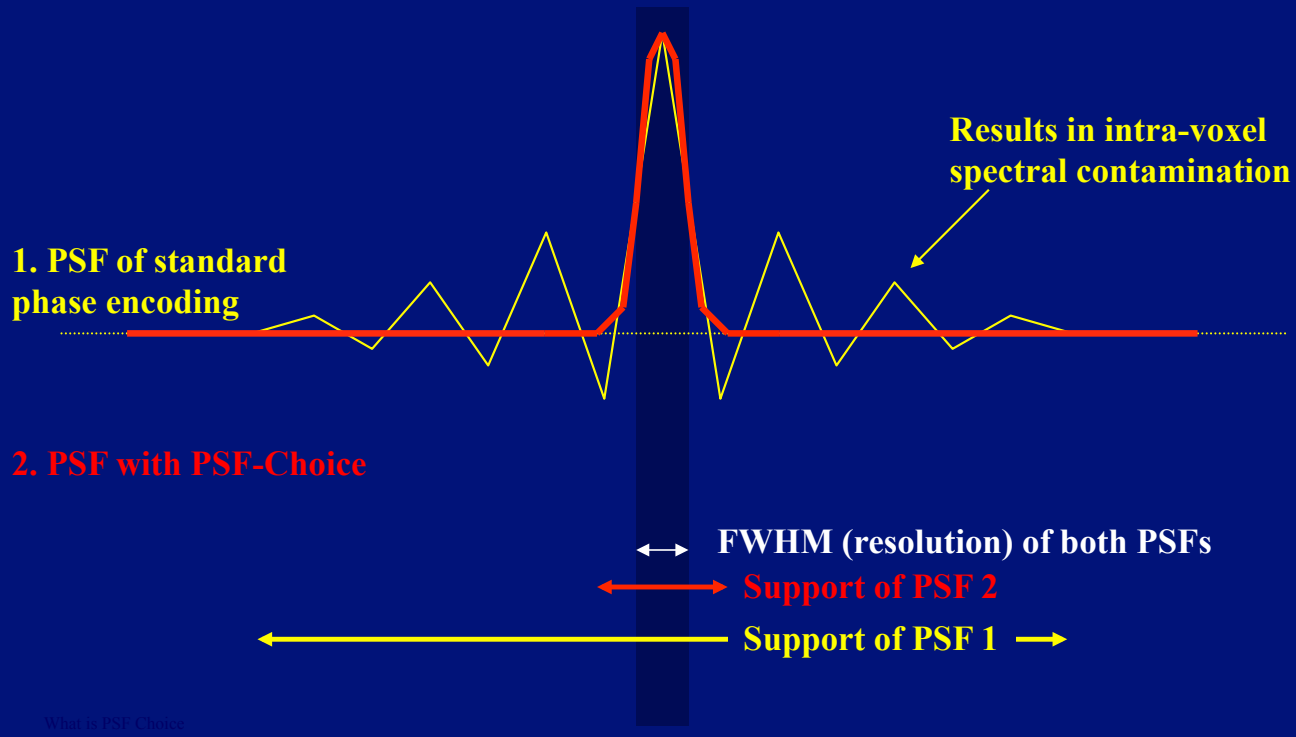
What is PSF-Choice ?

A method that improves the point-spread-function (PSF) and eliminates ringing artifact.



What is PSF Choice

Panych et al. Magn Reson Med 2005; 54(1):159-68.

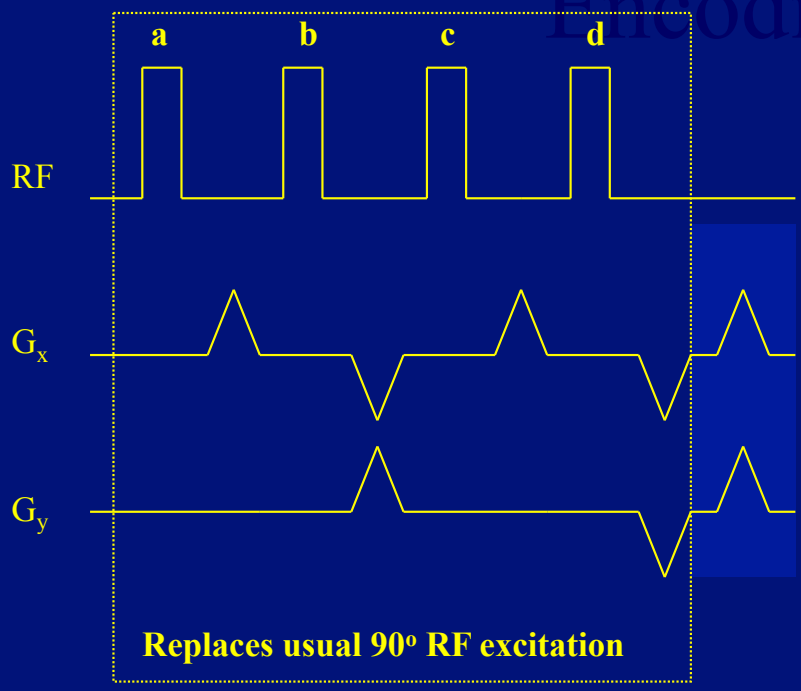
How is PSF-Choice implemented ?

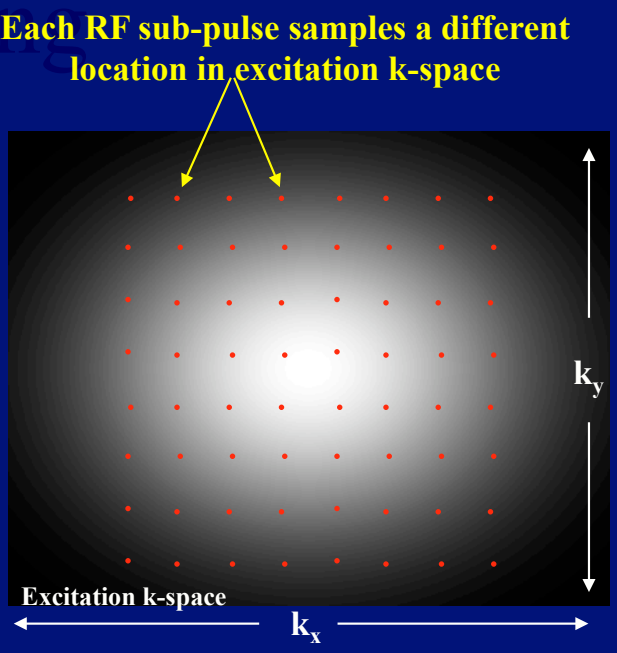
1. Replace the standard 90^{o} RF excitation pulse with a train of RF sub-pulses.
2. Change amplitudes of the sub-pulses on each excitation according to a weighting scheme that determines the resultant PSF.

How is PSF-Choice Implemented

Panych et al. Magn Reson Med 2005; 54(1):159-68.

Example: 4x4 PSF-Choice Encoding



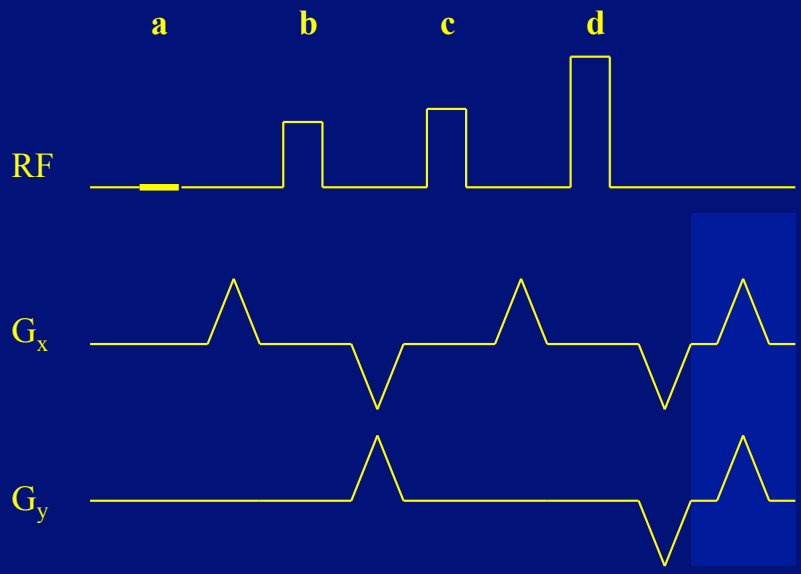


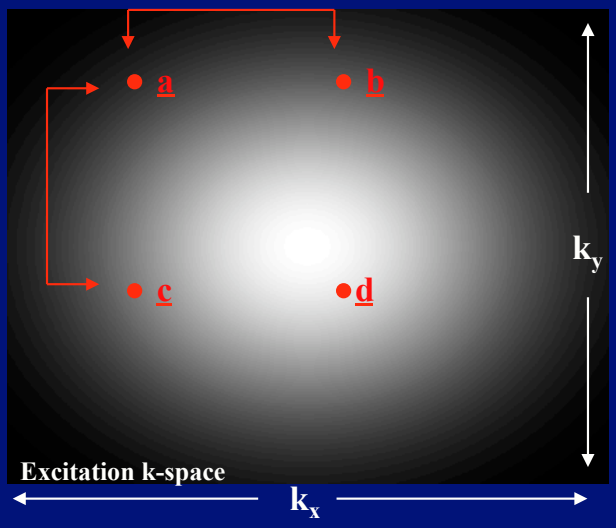
The standard RF excitation pulse is replaced with a train of 4 sub-pulses in our scheme. Amplitudes of the sub-pulses are changed on each excitation according to Gaussian k-space weighting.

Two-dimensional PSF-Choice Encoding

Two-dimensional PSF-Choice Encoding

K_x Encode 1 K_y Encode 1

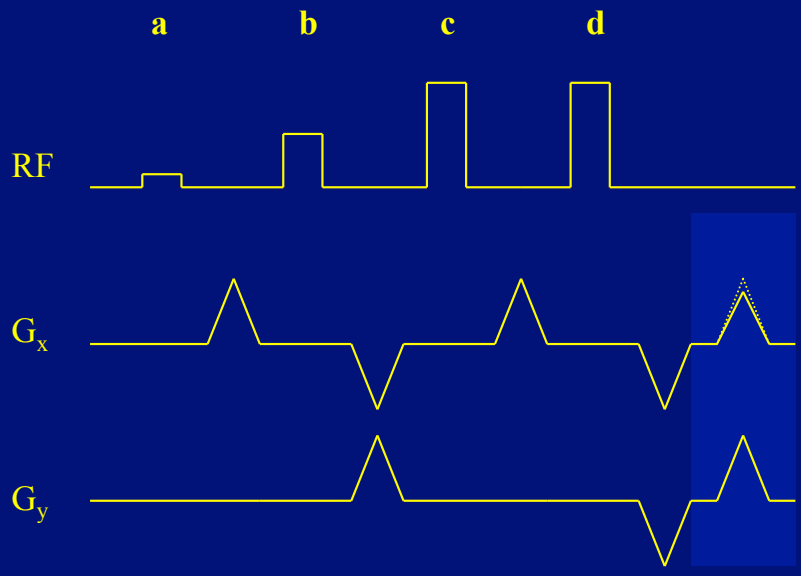


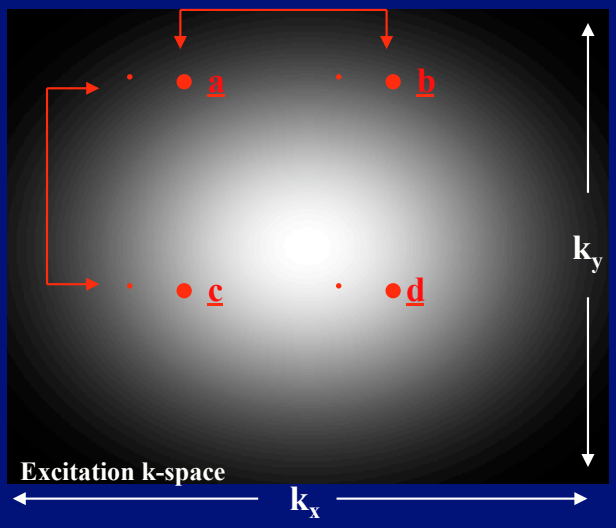


With each excitation a new set of 4 points in excitation k-space is sampled.

Two-dimensional PSF-Choice Encoding

K_x Encode 2 K_y Encode 1

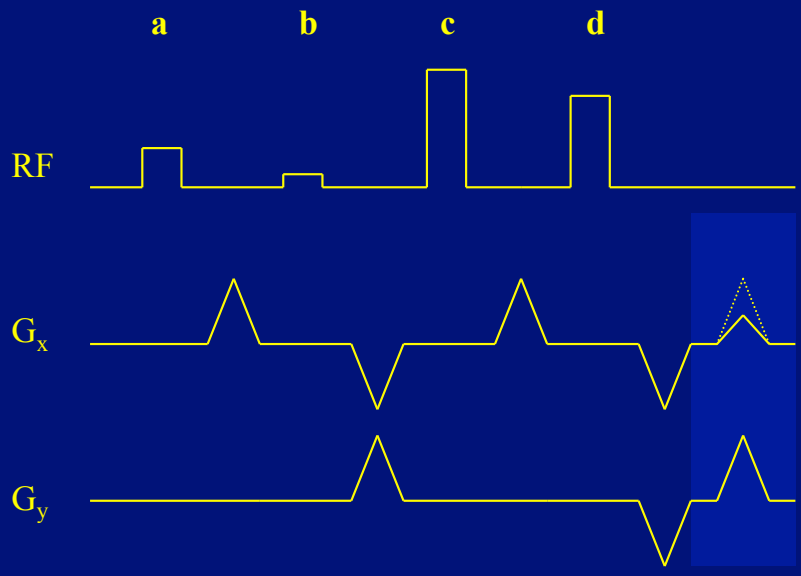


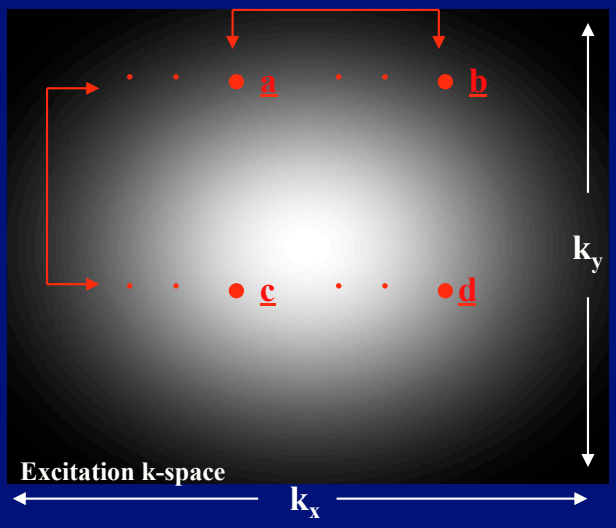


With each excitation a new set of 4 points in excitation k-space is sampled.

Two-dimensional PSF-Choice Encoding

K_x Encode 3 K_y Encode 1

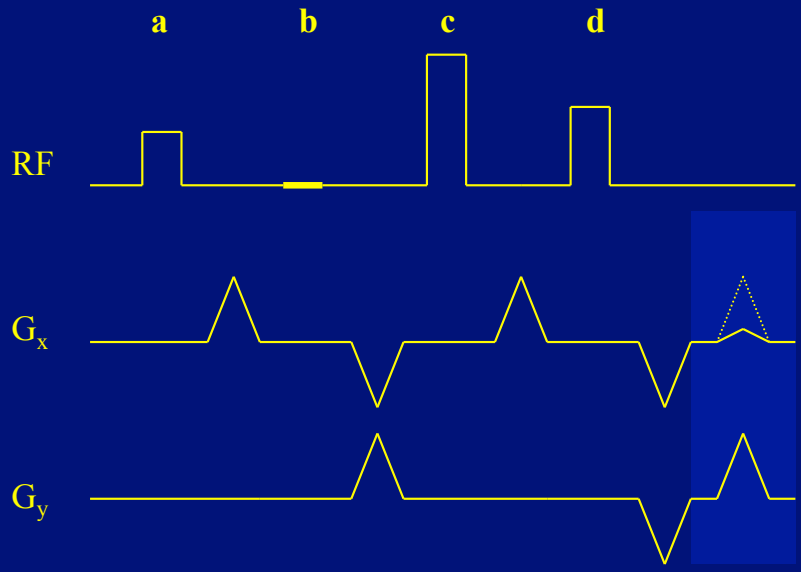


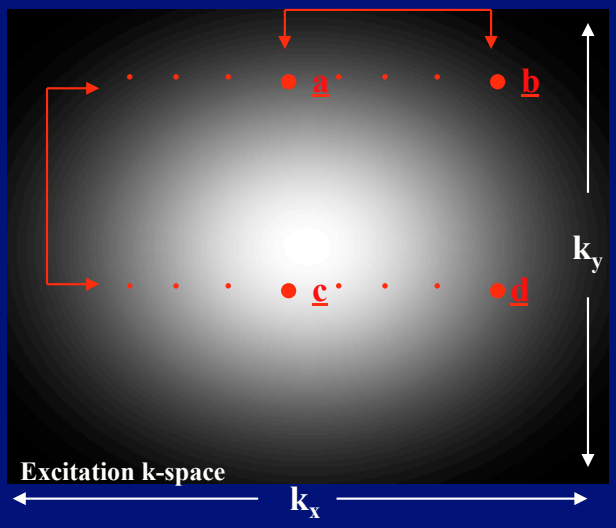


With each excitation a new set of 4 points in excitation k-space is sampled.

Two-dimensional PSF-Choice Encoding

K_x Encode **4** K_y Encode **1**

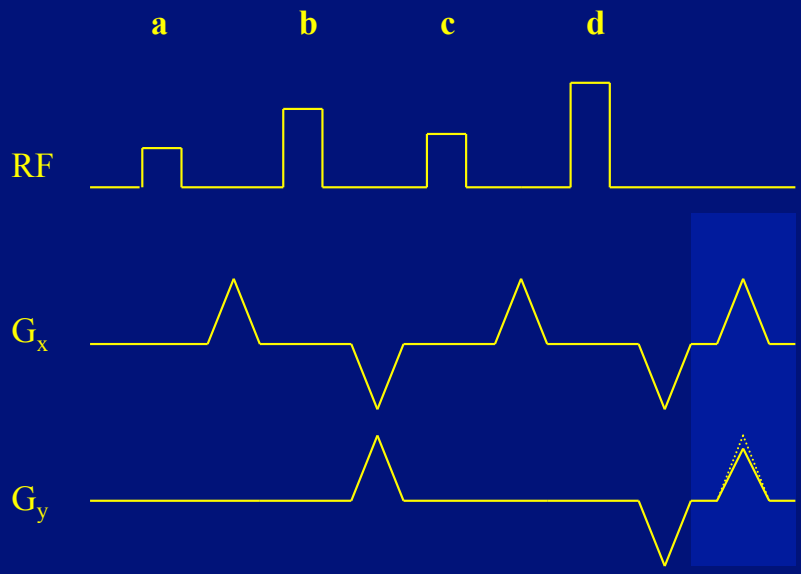


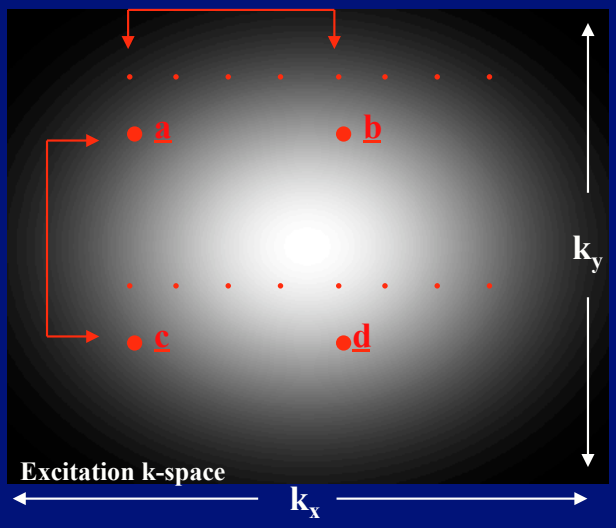


With each excitation a new set of 4 points in excitation k-space is sampled.

Two-dimensional PSF-Choice Encoding

K_x Encode 1 K_y Encode 2

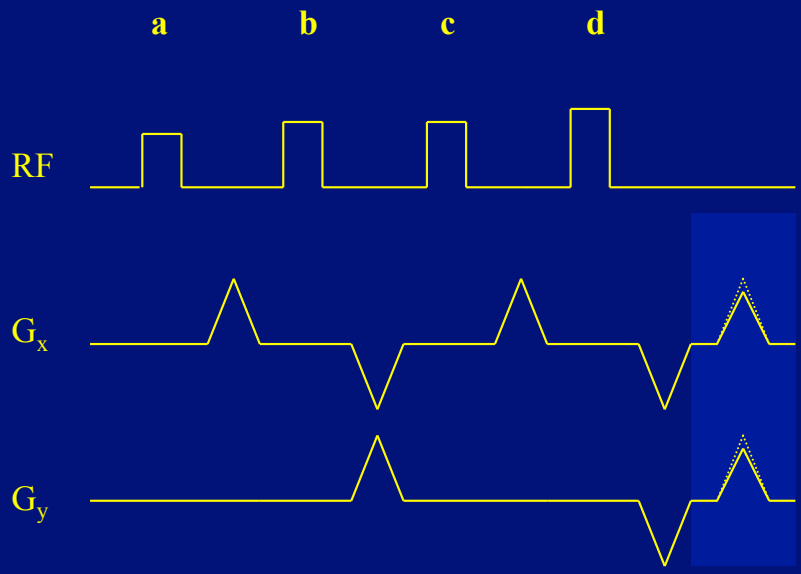


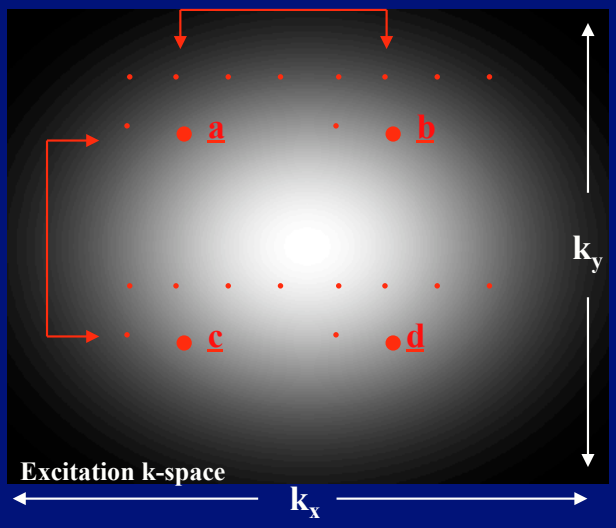


With each excitation a new set of 4 points in excitation k-space is sampled.

Two-dimensional PSF-Choice Encoding

K_x Encode 2 K_y Encode 2

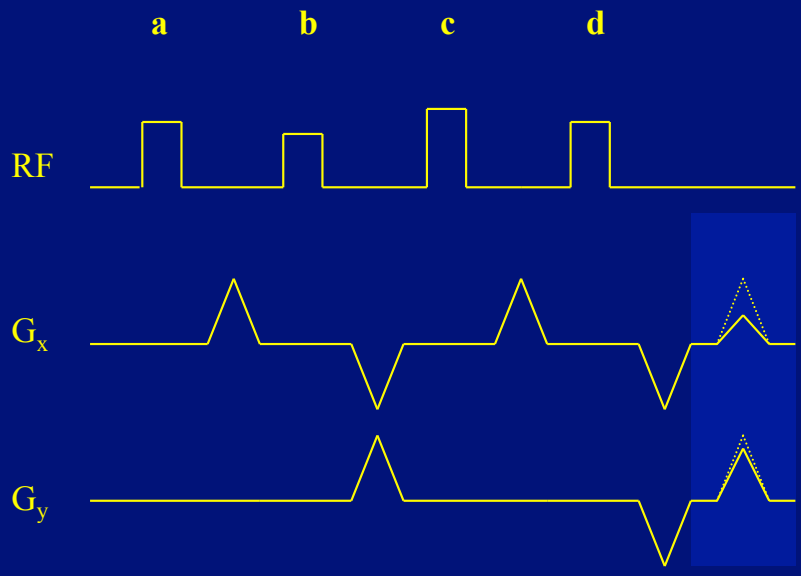


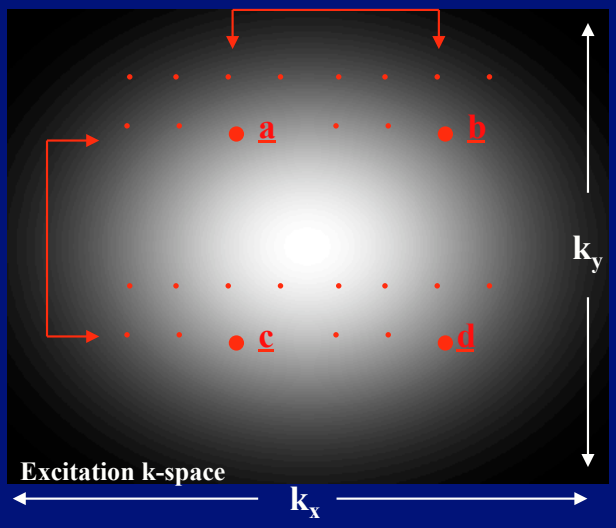


With each excitation a new set of 4 points in excitation k-space is sampled.

Two-dimensional PSF-Choice Encoding

K_x Encode **3** K_y Encode **2**

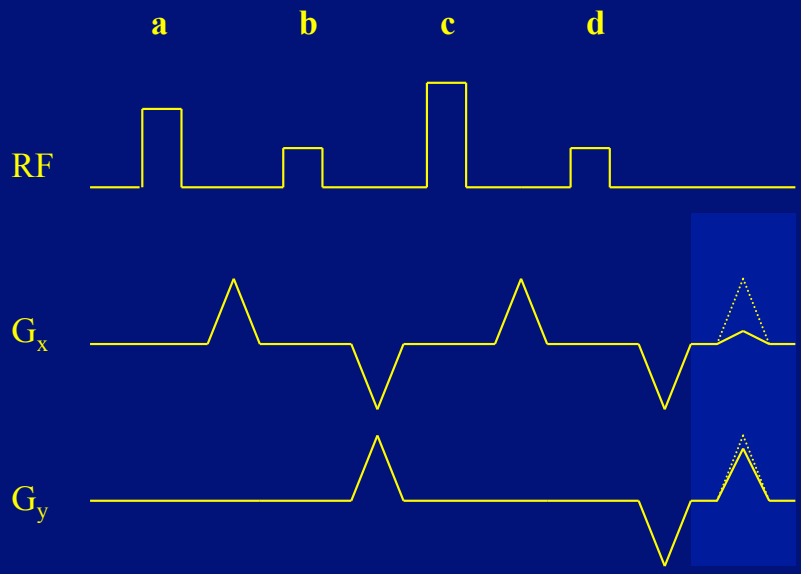


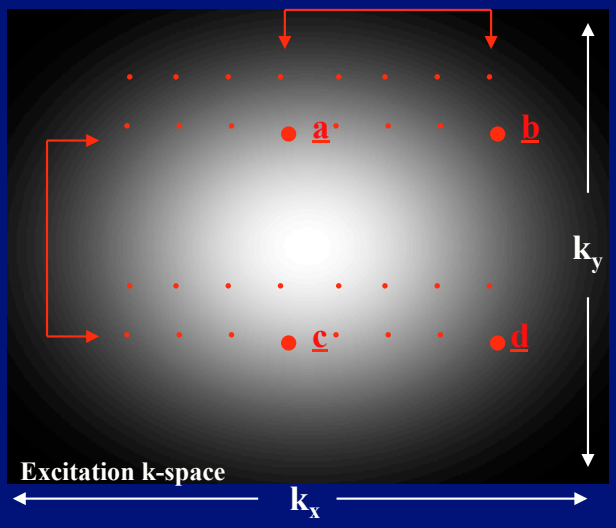


With each excitation a new set of 4 points in excitation k-space is sampled.

Two-dimensional PSF-Choice Encoding

K_x Encode 4 K_y Encode 2

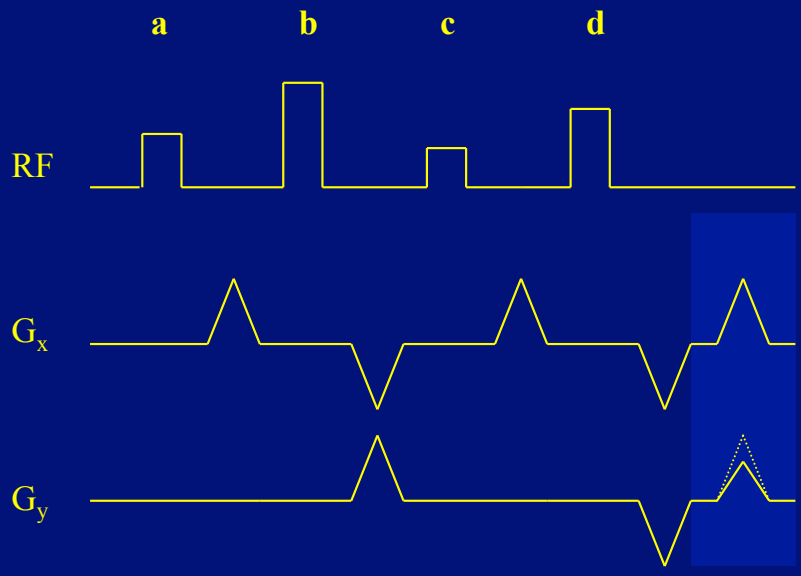


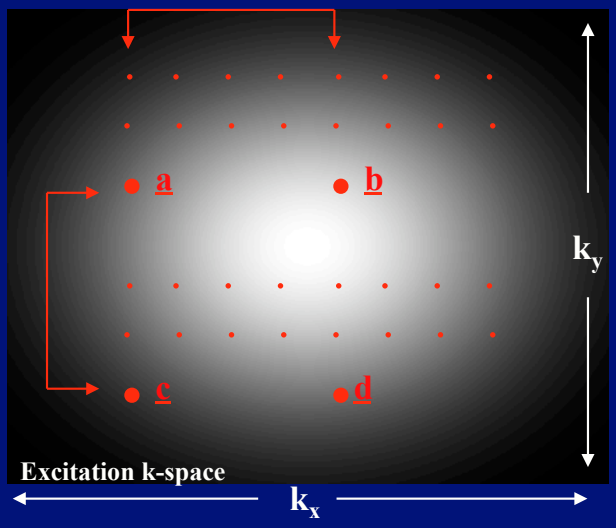


With each excitation a new set of 4 points in excitation k-space is sampled.

Two-dimensional PSF-Choice Encoding

K_x Encode **1** K_y Encode **3**

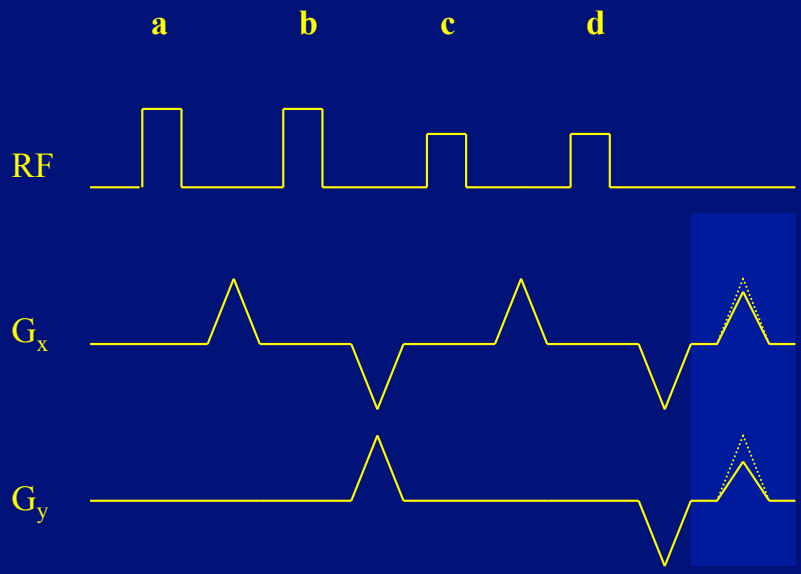


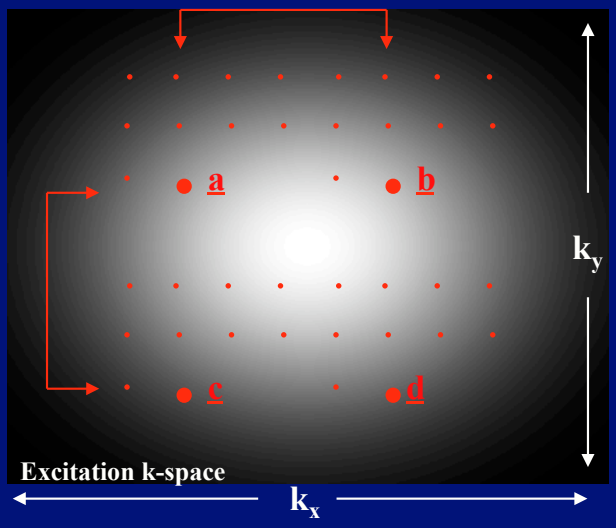


With each excitation a new set of 4 points in excitation k-space is sampled.

Two-dimensional PSF-Choice Encoding

K_x Encode **2** K_y Encode **3**

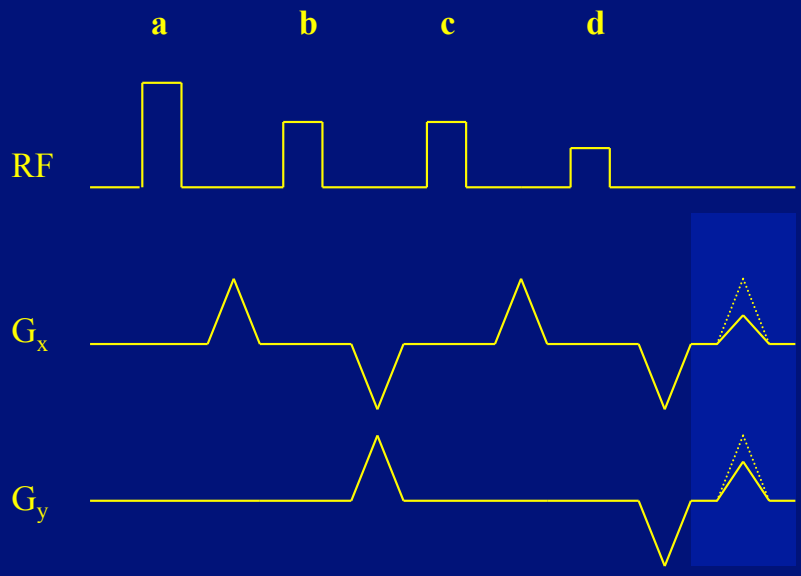


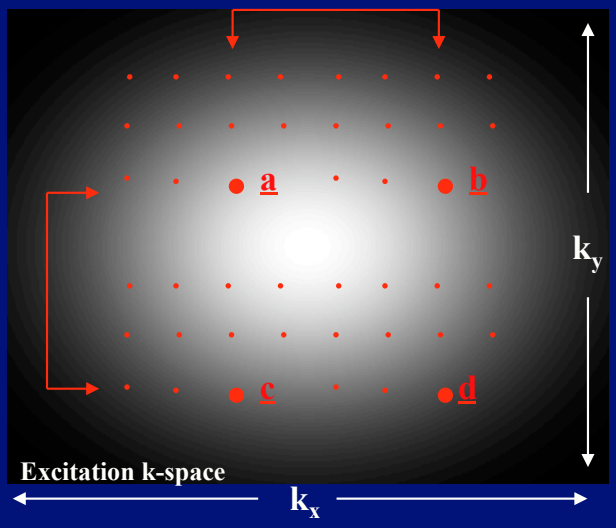


With each excitation a new set of 4 points in excitation k-space is sampled.

Two-dimensional PSF-Choice Encoding

K_x Encode 3 K_y Encode 3

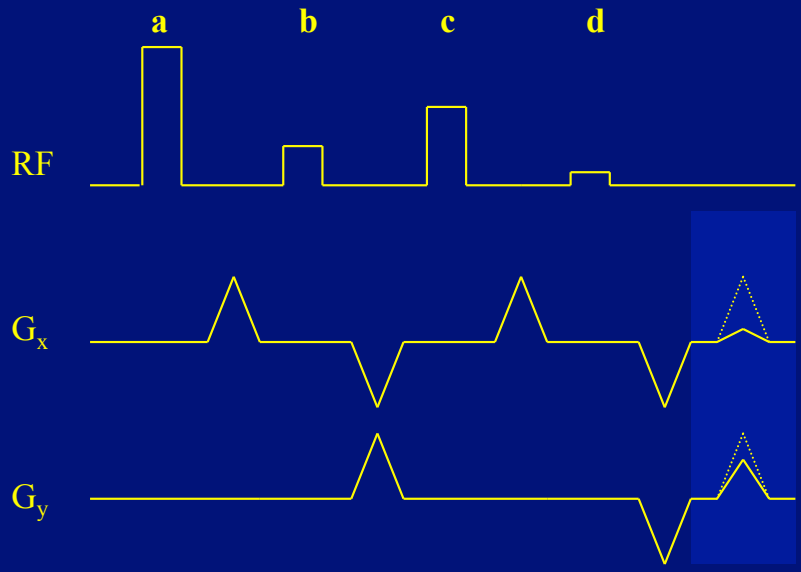


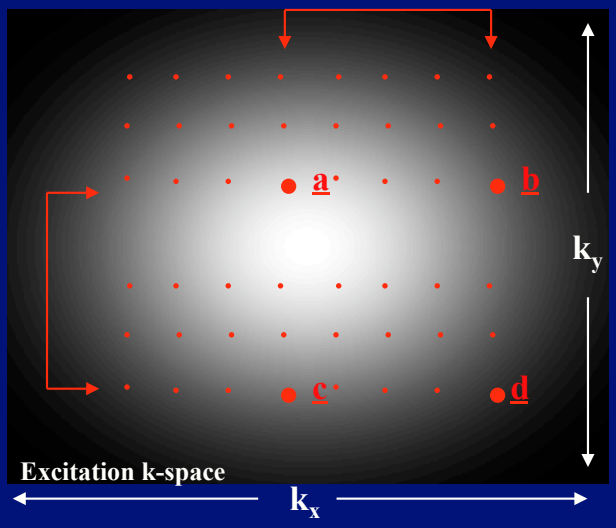


With each excitation a new set of 4 points in excitation k-space is sampled.

Two-dimensional PSF-Choice Encoding

K_x Encode **4** K_y Encode **3**

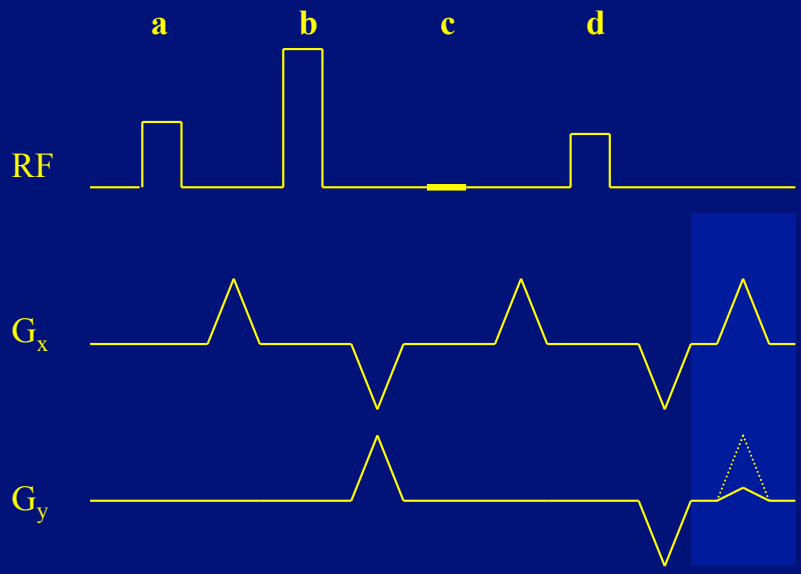


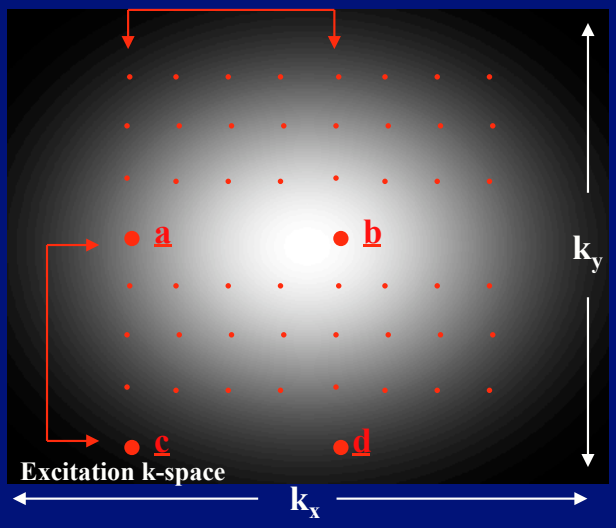


With each excitation a new set of 4 points in excitation k-space is sampled.

Two-dimensional PSF-Choice Encoding

K_x Encode **1** K_y Encode **4**





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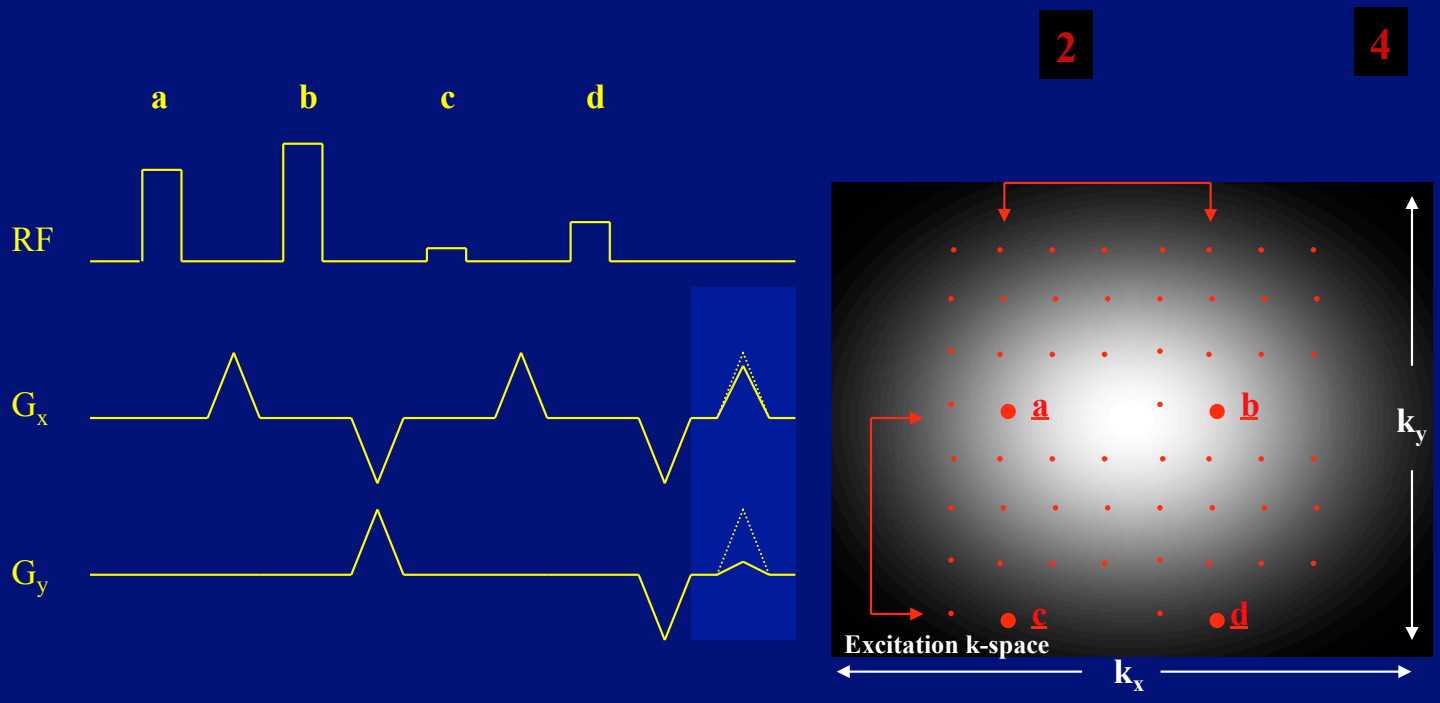

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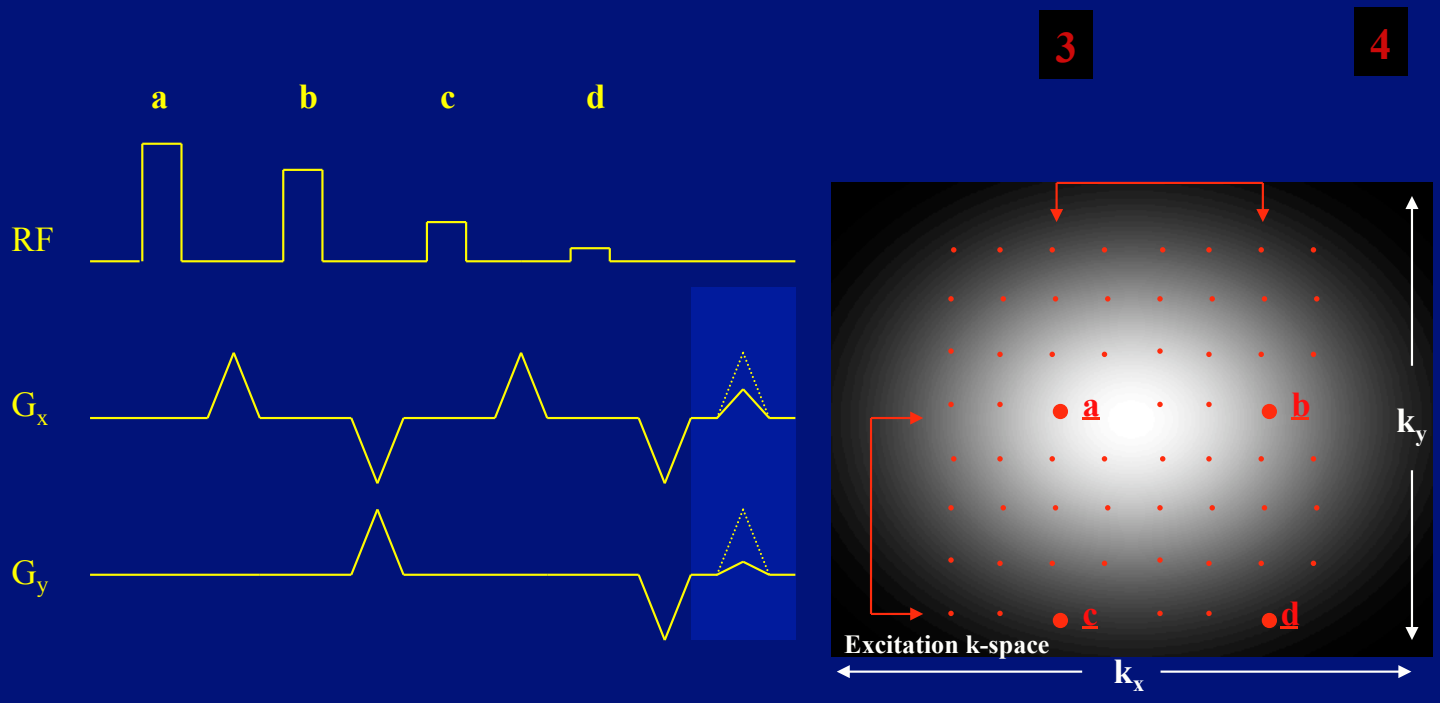

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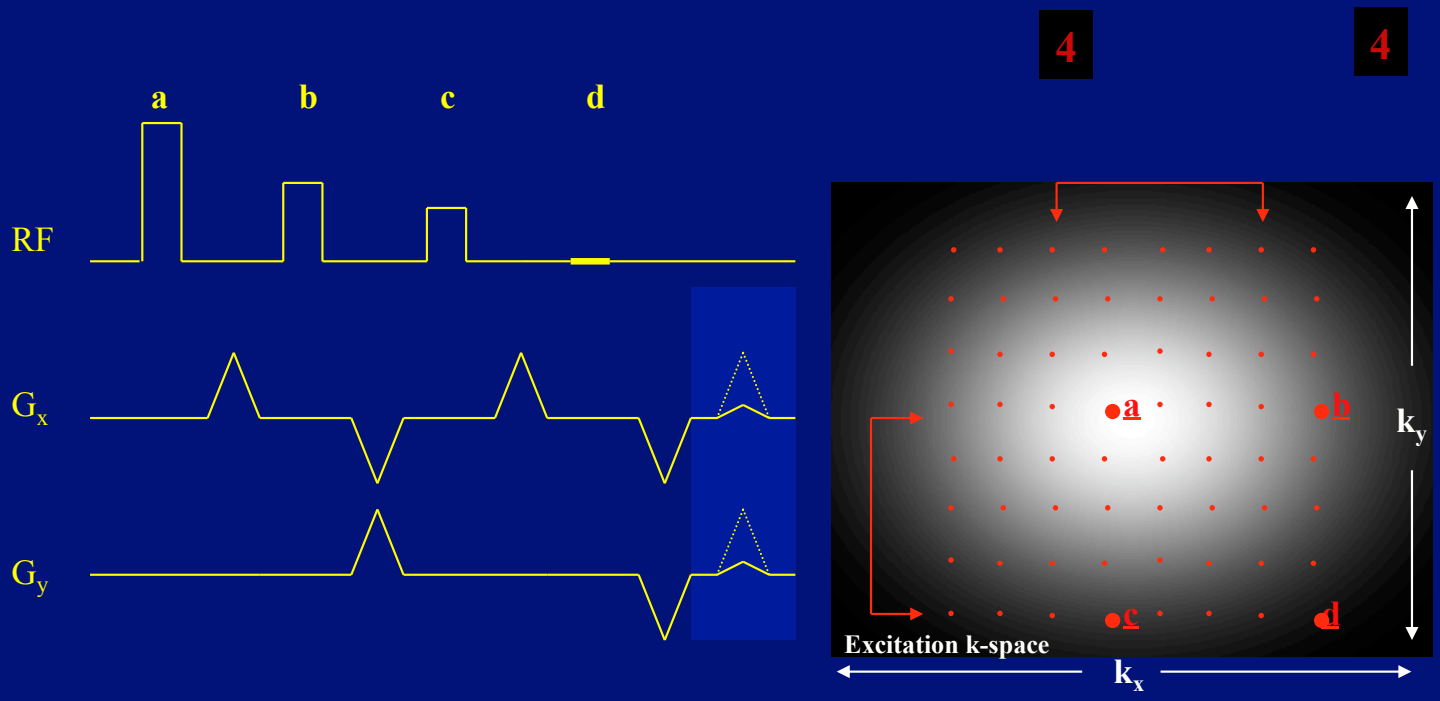

With each excitation a new set of 4 points in excitation k-space is sampled.

2D PSF-Choice Reconstruction

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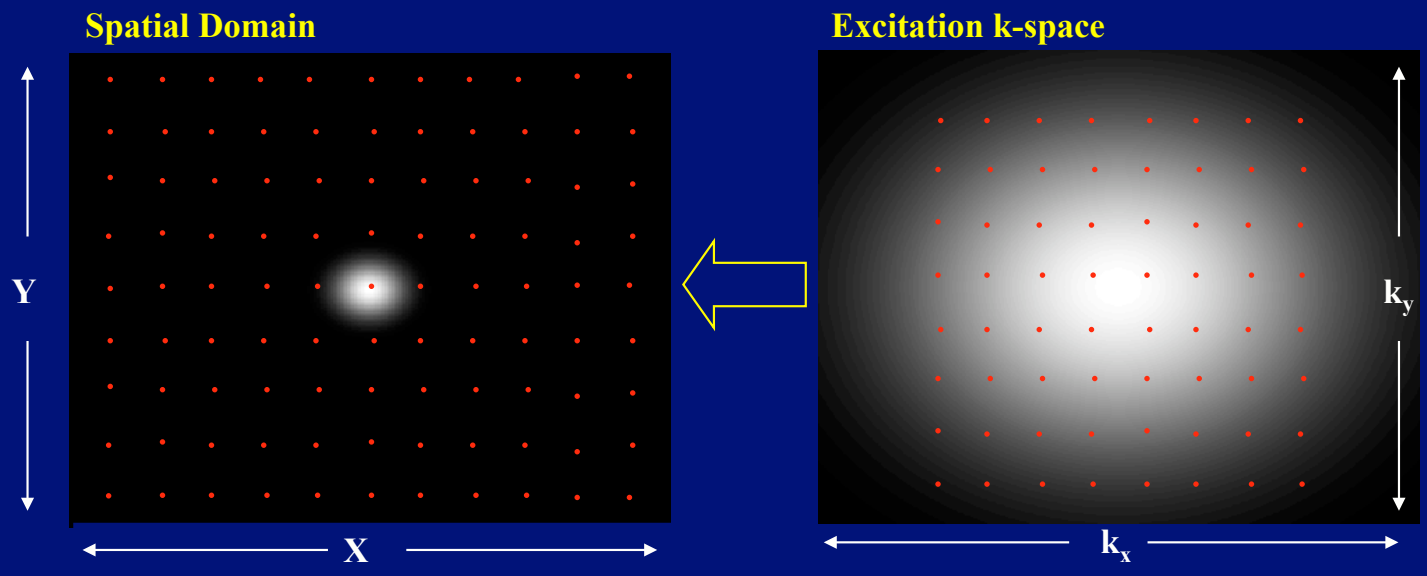
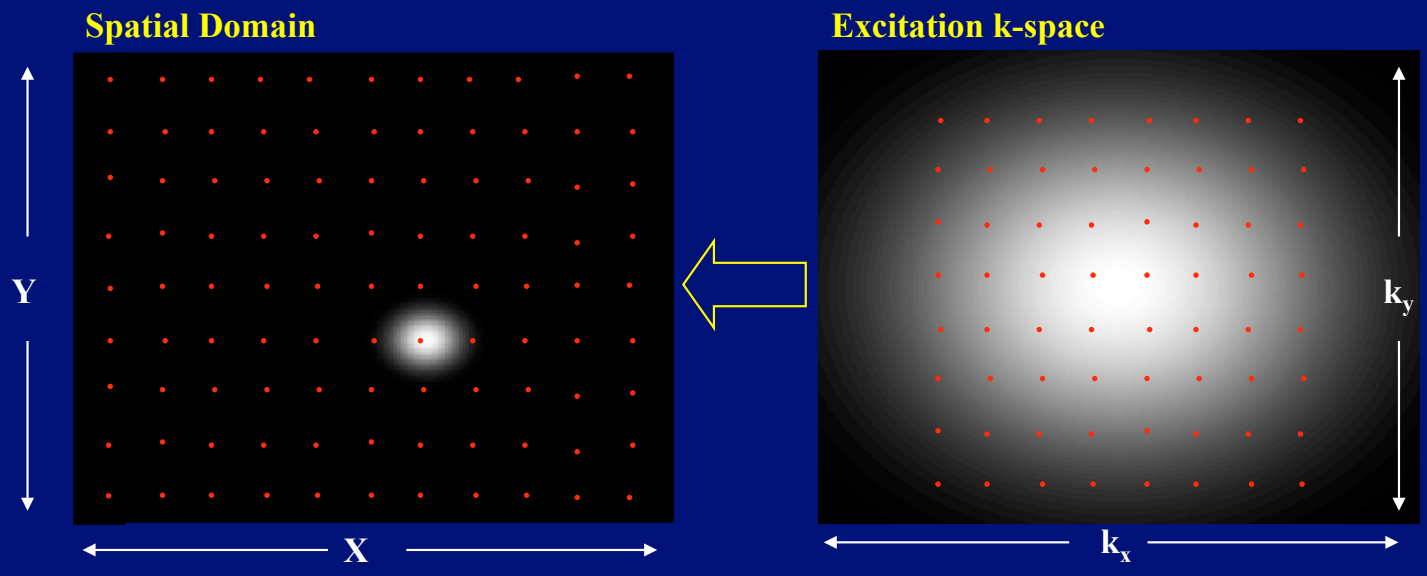
When combining the results from all excitations, the net effect is excitation of a Gaussian-shaped 'virtual profile' in the PSF-encoding directions, X and Y.



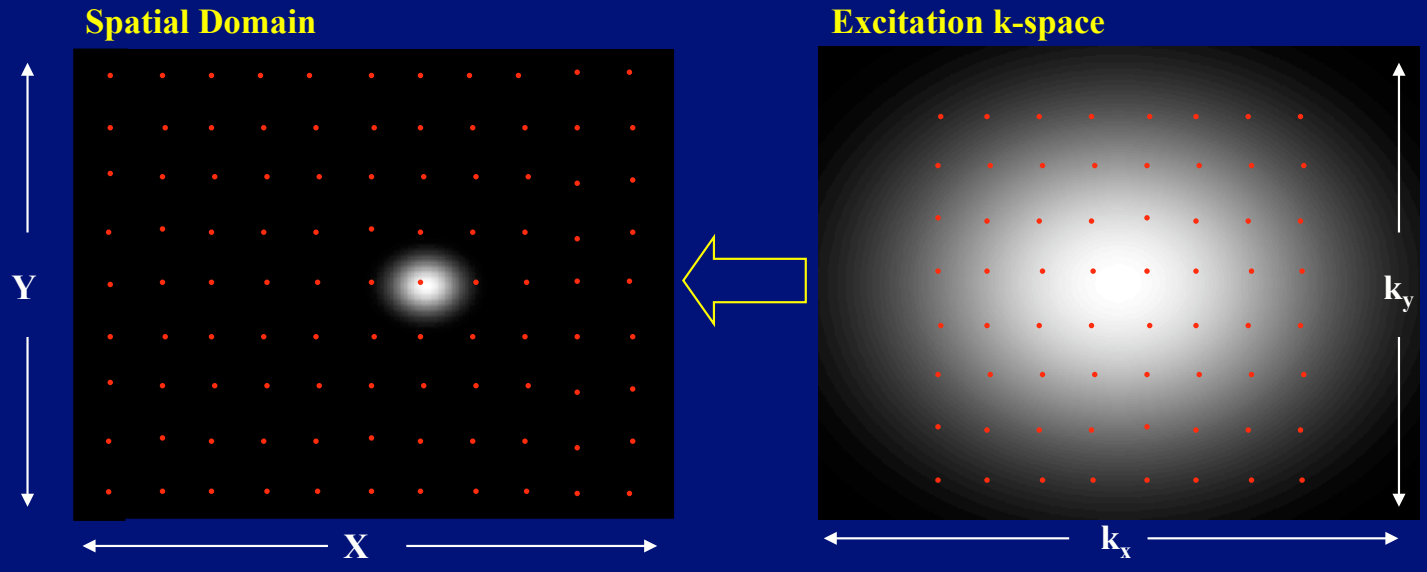
2D PSF-Choice Reconstruction

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

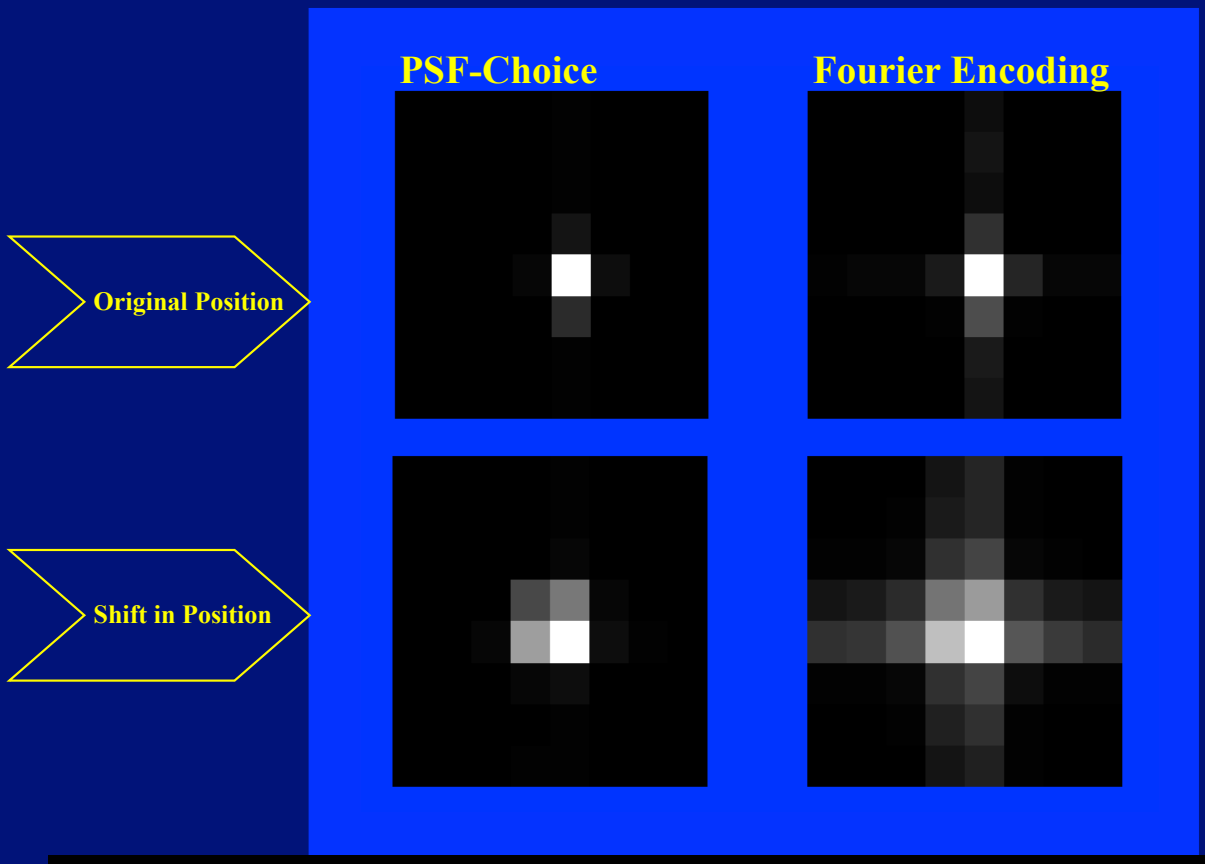
For a NxN PSF-Choice encoding,
spectra from NxN different locations can be reconstructed.
The effective PSF is determined by the shape
of the virtual profile - e.g., a Gaussian PSF in our case.



PSF-Choice Encoding vs Fourier Encoding: Results in Phantom

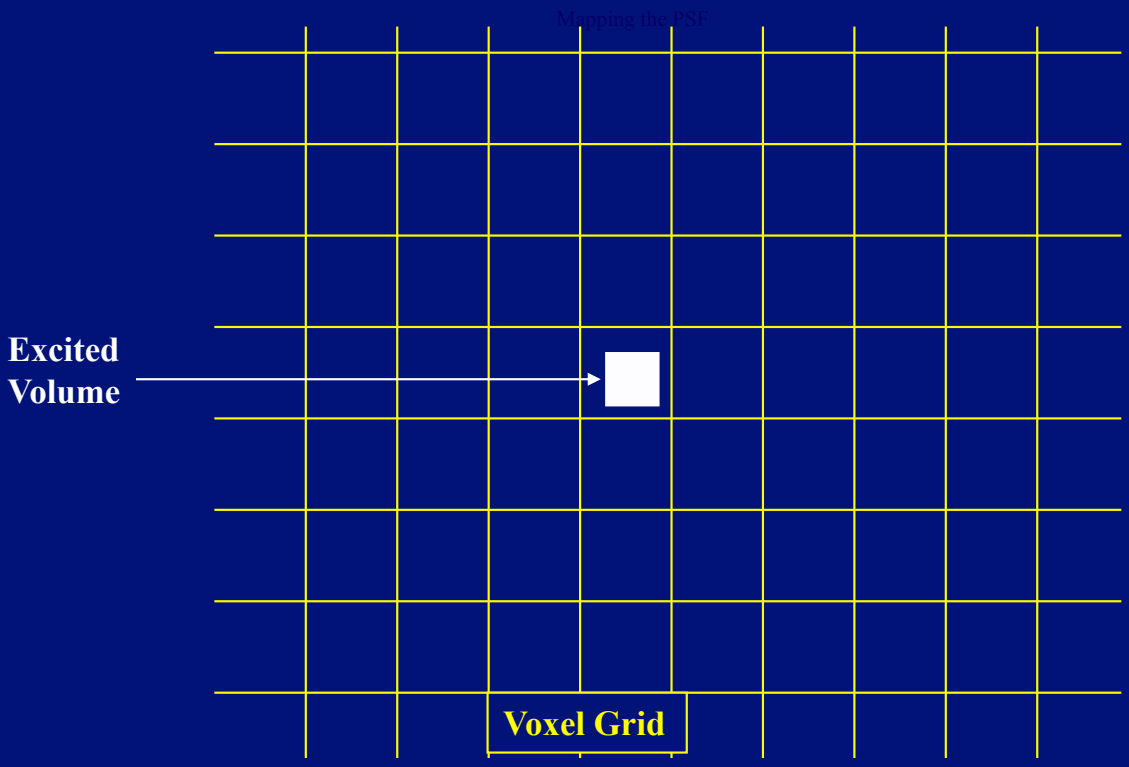
- GE 3T Signa System (15M4).
- 3D MRSI acquisitions:
  - PSF-Choice encoding in *x* and *y*
  - EPSI in *z*.
- GE Quadrature head coil.
- GE MRS phantom.

PSF-Choice Encoding vs Fourier Encoding



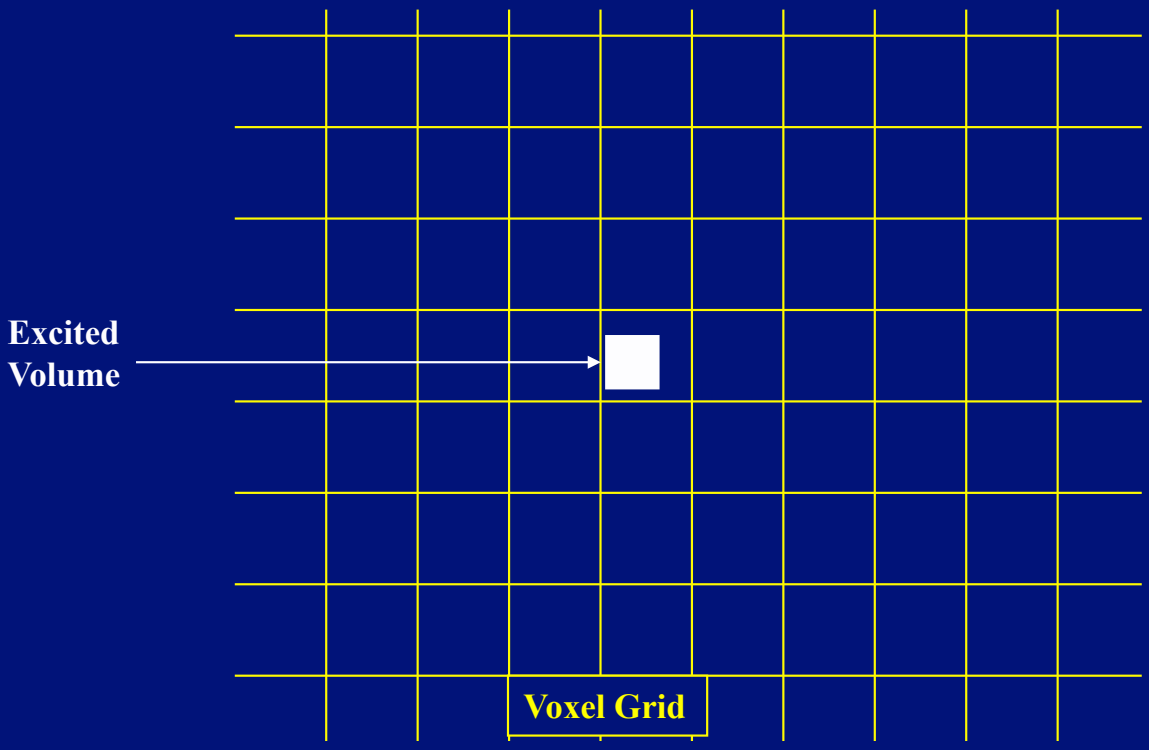
8 x 8 images of H_2O peak. *Selected volume is smaller than voxel size*

Mapping the Point-Spread-Function



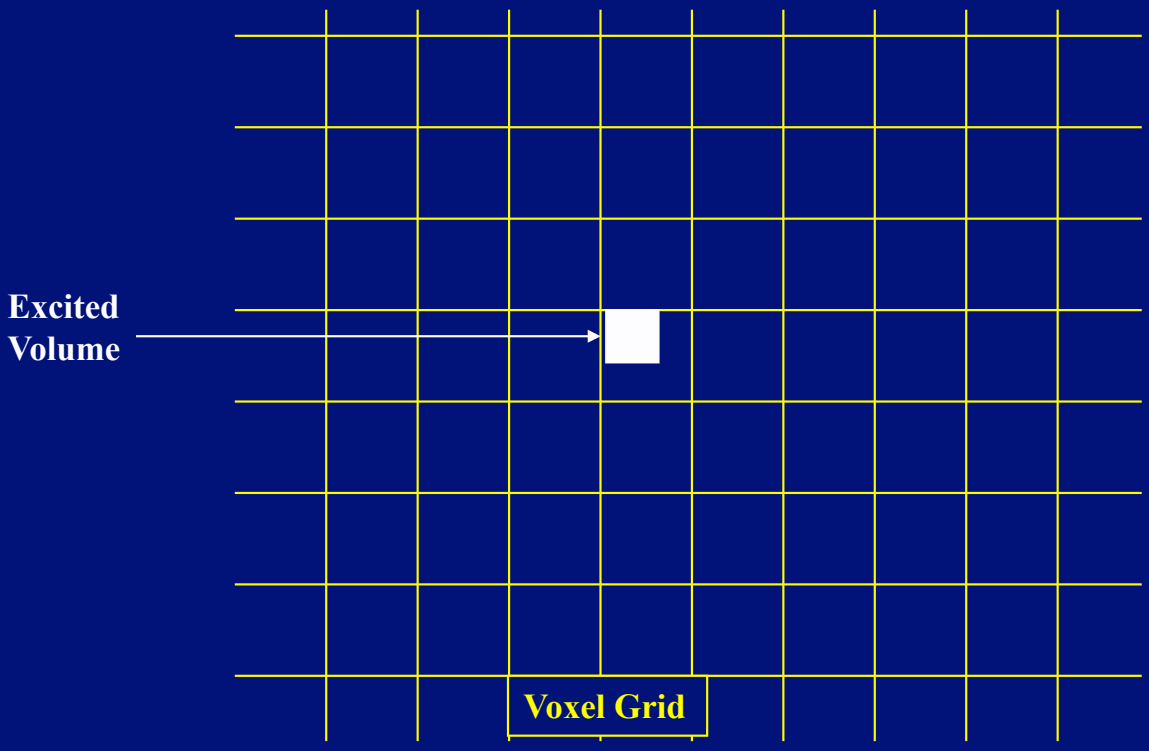
Excite a small volume and acquire multiple image sets with 1/4-voxel shifts in each direction (4x4 shifts =16 acquisitions)

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)

Mapping the Point-Spread-Function



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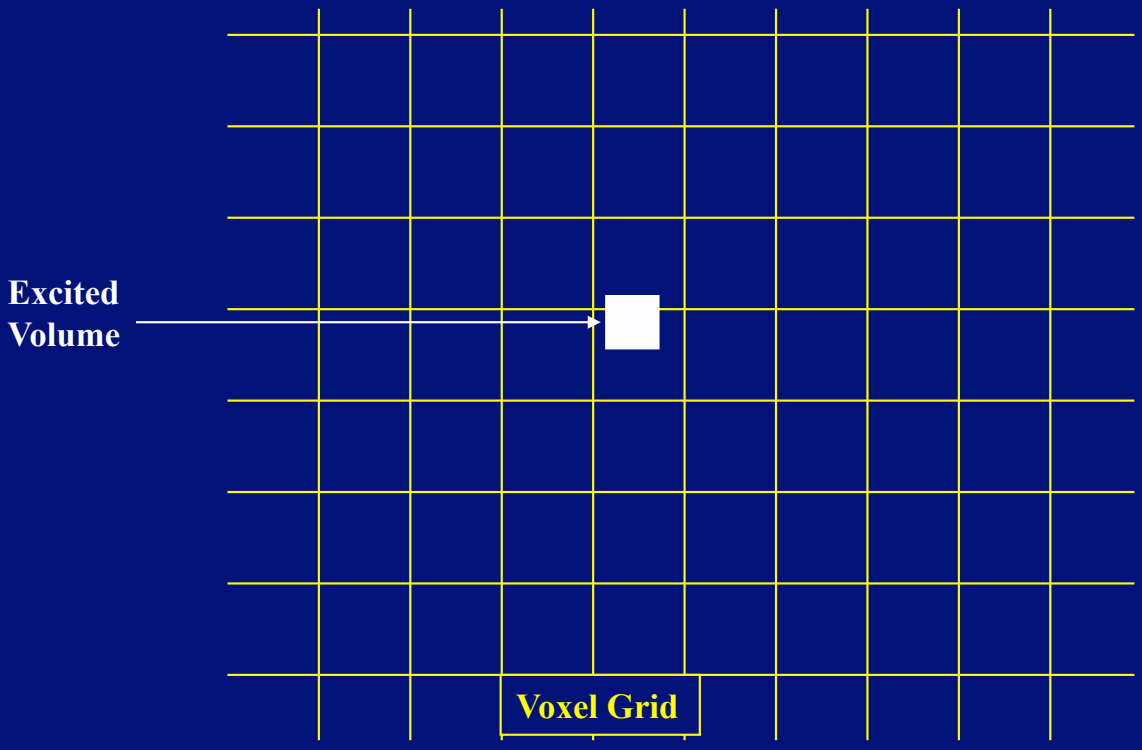
Mapping the Point-Spread-Function



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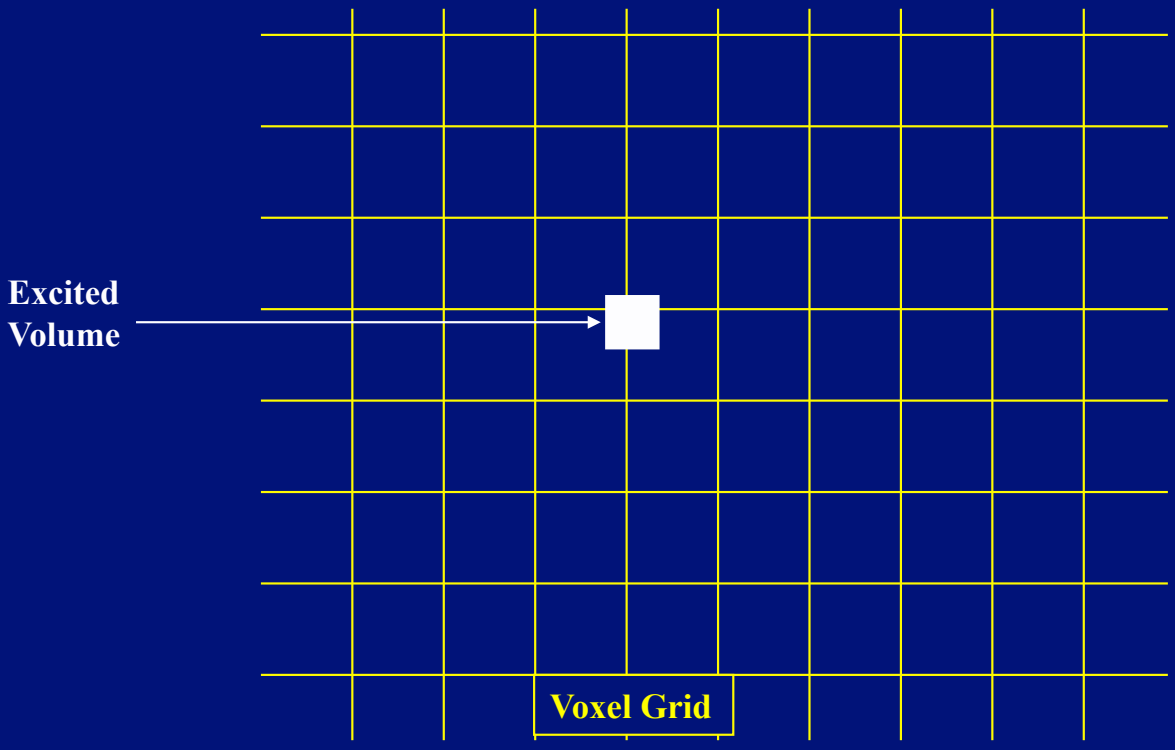

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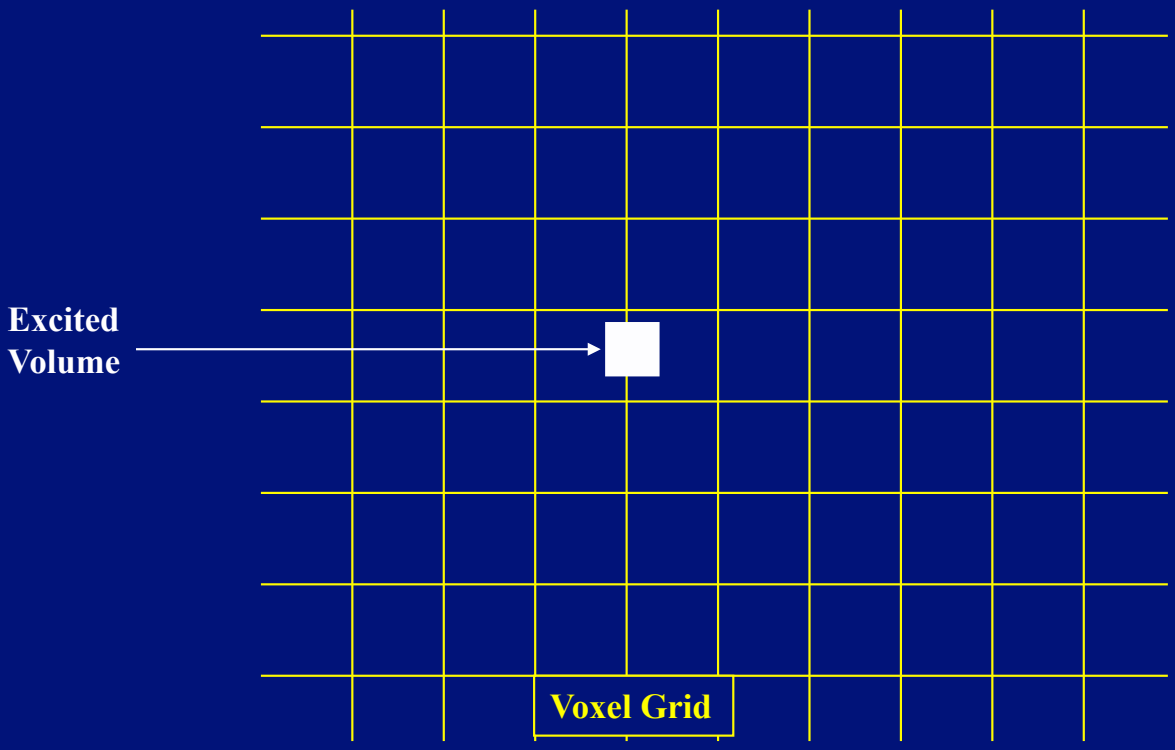
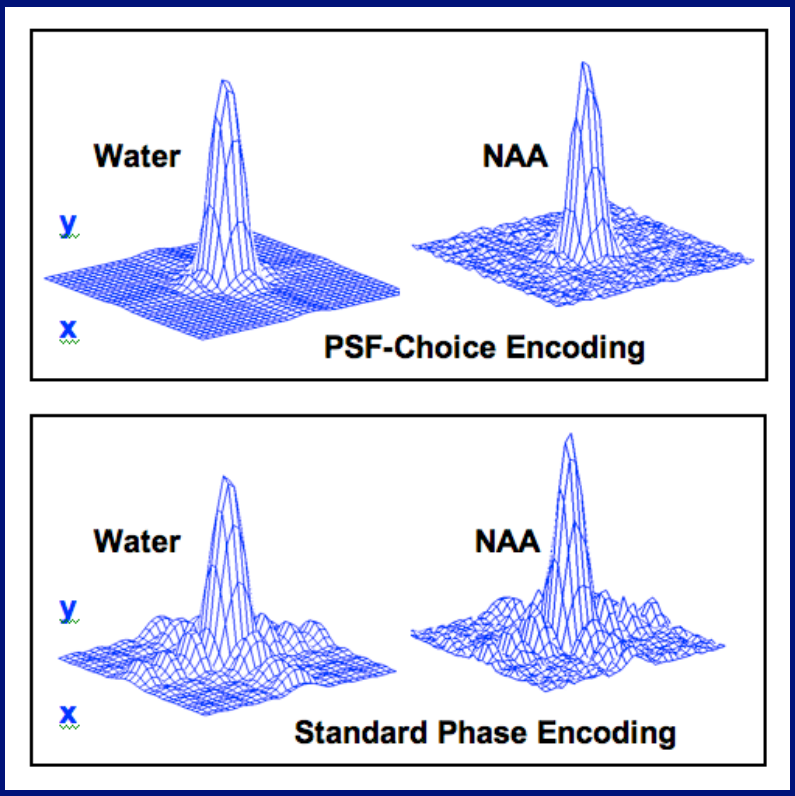
Mapping the Point-Spread-Function



Excite a small volume and acquire multiple image sets with 1/4-voxel shifts in each direction (4x4 shifts =16 acquisitions)

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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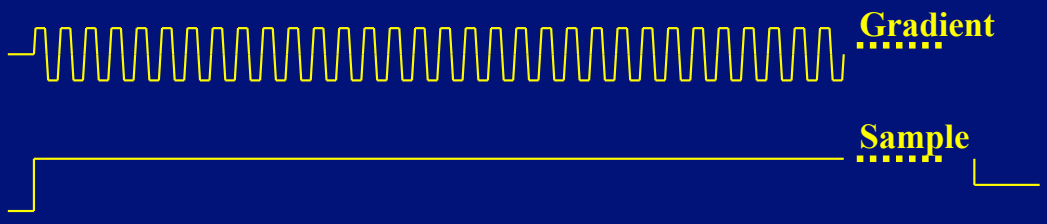
Echo-Planar Spectroscopic Imaging (EPSI)

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



Posse et al. Magn Reson Med 1995; 33(1):34-40.

PRESS compared to EPSI with PSF-Choice

PRESS vs EPSI with PSF-Choice

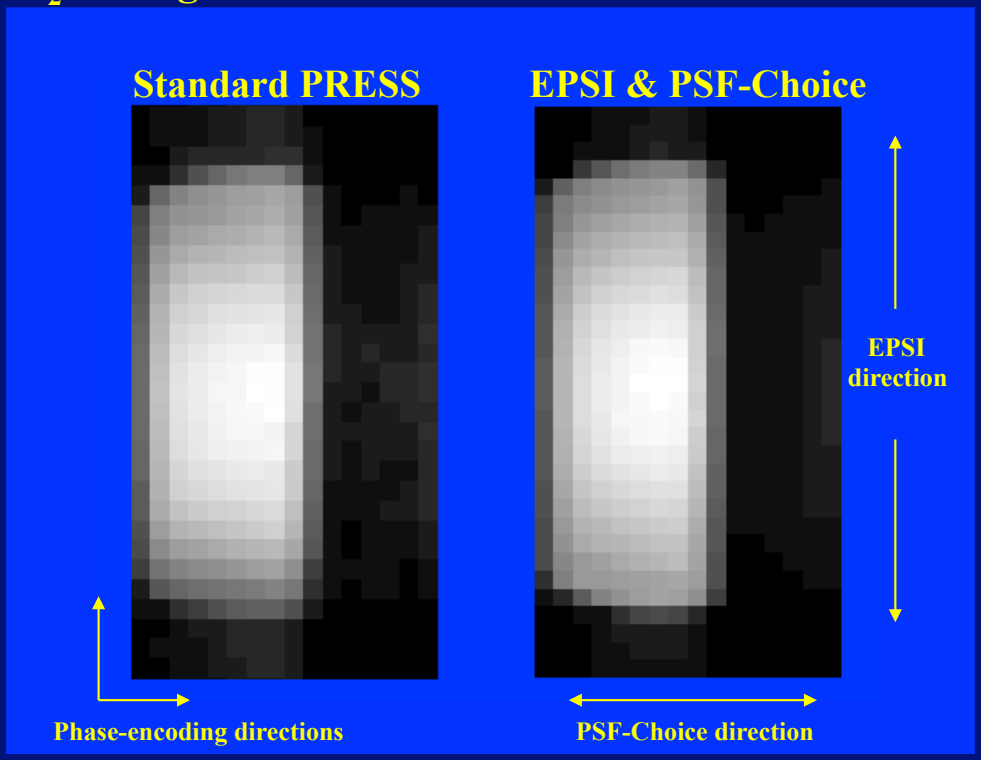
FOV = 24x12 cm

Acquisition Matrix
PRESS:
32x16x512 - *1 average*
EPSI & PSF-Choice:
32x16x512 - *32 averages*

TE/TR = 85/1000 msec

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

H_2O images



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]).**

1. Panych et al. Magn Reson Med 2005; 54(1):159-68.
2. Posse et al. Magn Reson Med 1995; 33(1):34-40.
3. Irani and Peleg. 10th Int Conf Pattern Recogn 1990; 2:115-120.

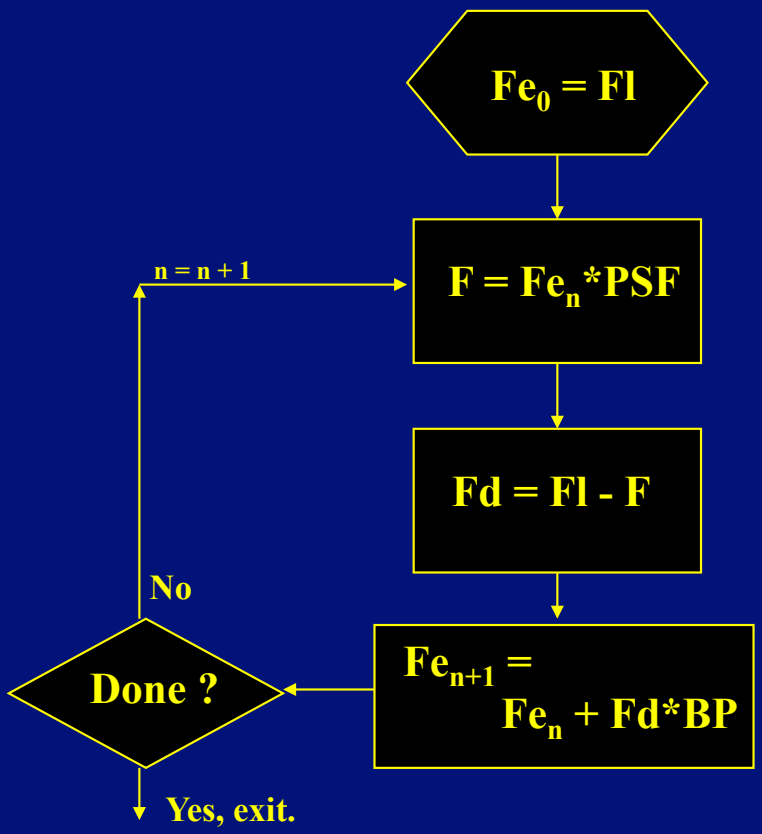
Resolution Enhancement (or 'super resolution')

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, Fe, 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, Fd, between the measured low-resolution data and the low-resolution estimate.

Update high resolution estimate by adding the error, Fd, convolved with a back-projection kernal, BP.

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

Resolution Enhancement: Phantom Results

Resolution Enhancement: Phantom Results

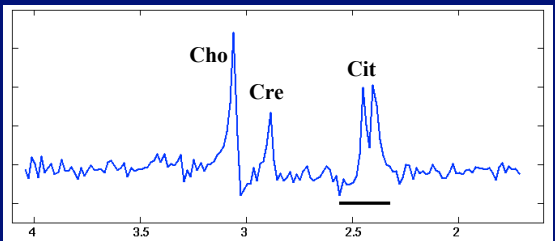
Standard Phase Encoded MRSI datasets: H^2O images.

PSF-Choice Encoded MRSI datasets: H^2O images.

Data was acquired using GE 'resolution' phantom.
Four acquisitions with 1/2 pixel shifts in x and y.

Resolution Enhancement With Noisy MRSI Data

Resolution Enhancement: With noisy MRSI data



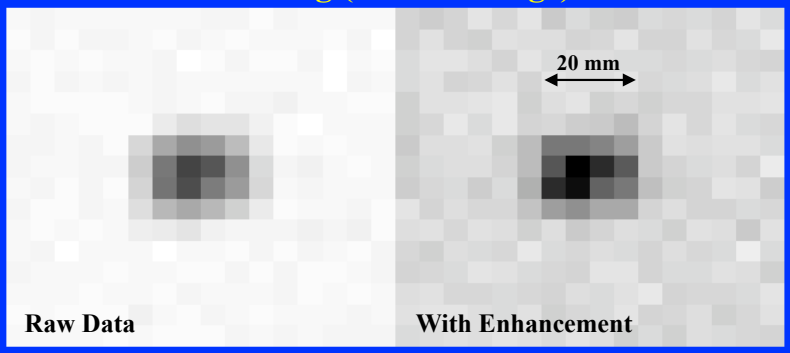
FOV = 80mm^3
Press voxel = cube; 20mm^3

Acquisition matrix = 8x8x8

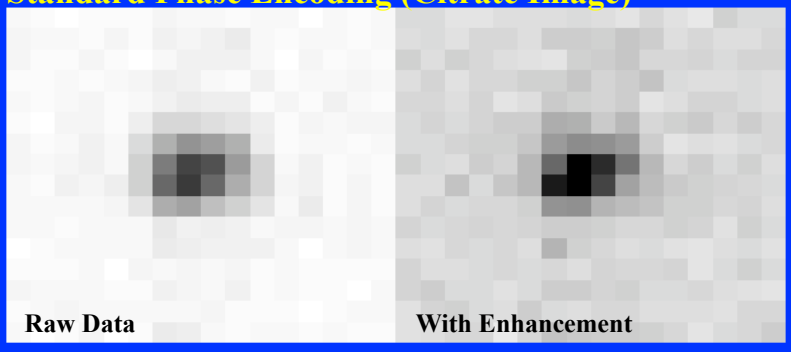
Four acquisitions:
Half pixel shifts in two directions, reconstructed and combined using super-resolution algorithm.

Citrate image: 2.32 to 2.56 ppm.

PSF-Choice Encoding (Citrate Image)



Standard Phase Encoding (Citrate Image)



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

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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