K-Space Trajectories and Spiral Scan

Presented by:

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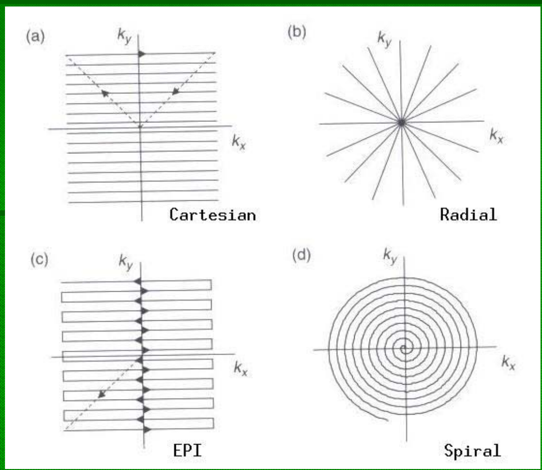
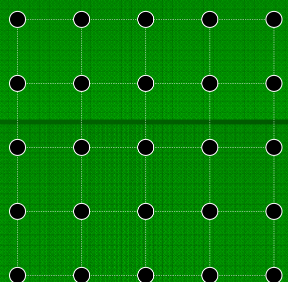
Outline

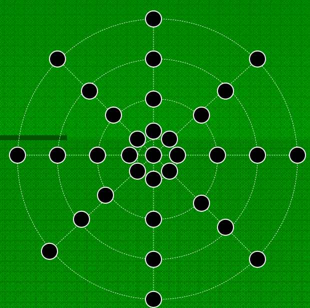
- K-space Trajectories
- Gridding Reconstruction
- Features of Spiral Sampling
- Pulse Sequences
- Mathematical Basis of Spiral Scanning
- Variations of Spiral-Out Sampling
- Hardware Considerations
- Comparison with Rectilinear Sampling
- An Application

Types of K-Space Trajectories

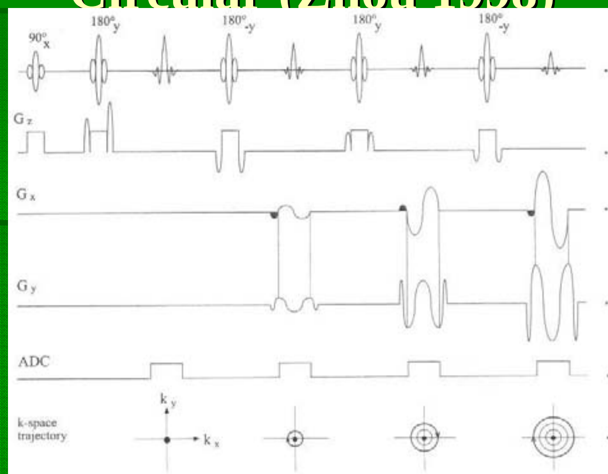


Sampling of K-Space

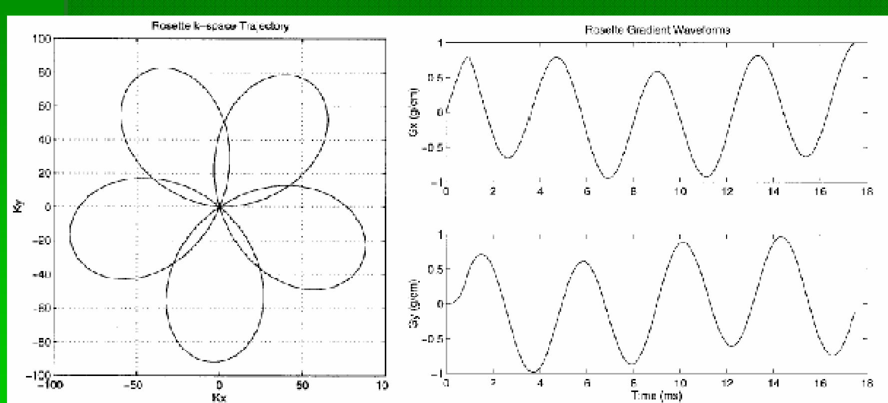




Other Non-Cartesian Trajectories: Circular (Zhou 1998)



Other Non-Cartesian Trajectories: Rosette (Noll 1997)



Reconstruction of Non-Cartesian Sampled Data (Gridding)

- Sampled data → Convolution in k-space → Rectilinearly resample data → "Normal" reconstruction

$$S^{(c)}(m\Delta k) = \sum_i S(k_i) g(m\Delta k - k_i) \Delta k_i^{(s)}$$

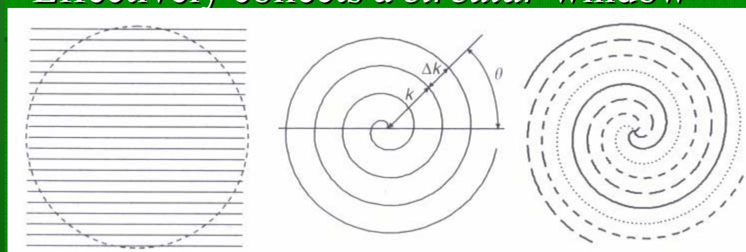
- Choice of convolution function depends upon processing time and interpolation accuracy

Why use Non-Cartesian Trajectories?

- Effectively faster scanning possible
- Efficient coverage of k-space
- Off-resonance spins result in blurring in spiral scans, rather than geometric distortion
- Usually robust to motion

The Spiral Trajectory

- Developed by Ahn CB, *et al.*, 1986
- Samples k-space data in a *spiral* manner
- Effectively collects a *circular* window

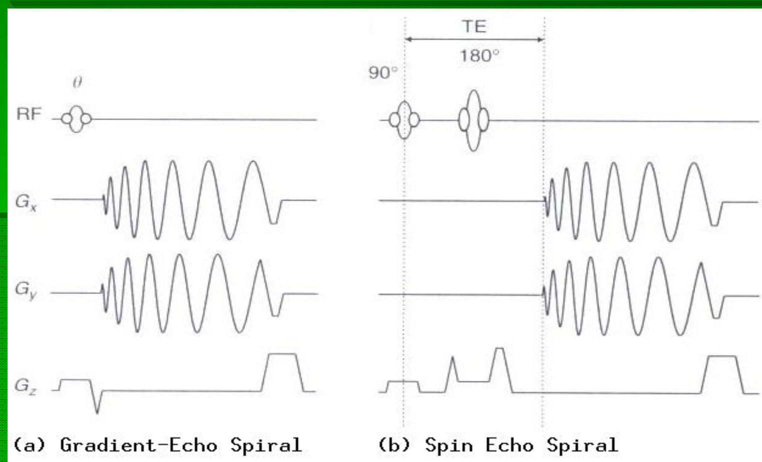


(a) Coverage (b) Single-shot (c) Interleaved

Some Features

- Allows a flexible tradeoff between the number of shots, and amount of data per shot
- Can be combined with MRI techniques
- 2-D readout function in X and Y
- Central over-sampling reduces sensitivity to motion
- Adjustable echo time

The Basic Pulse Sequence



Some Math…

- Let $k_x = k \cos\theta$ and $k_y = k \sin\theta$
- The spiral trajectory: $k(t) = \lambda\theta(t)$
- For alias-free sampling satisfying the Nyquist criterion radially,

$$\lambda = \frac{N_{shot}}{2\pi L}$$

- To satisfy the azimuthal Nyquist requirement,

$$\frac{\gamma}{2\pi} G_0 L = 2\Delta\upsilon$$

Some more Math…

- The maximum k-space radius is defined by

$$k_{\max} = \frac{N}{2L}$$

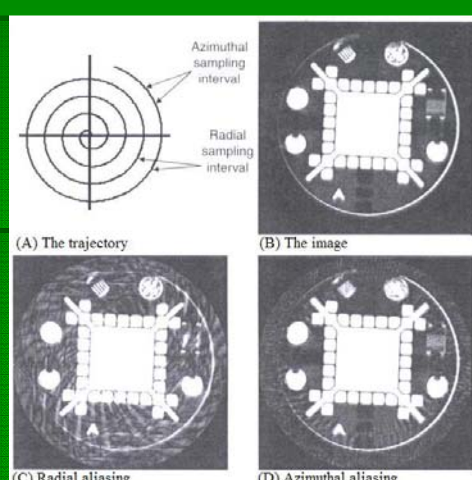
- From the equation for the spiral trajectory, we can get,

$$\theta_{\max} = \frac{k_{\max}}{\lambda} = \frac{\pi N}{N_{shot}}$$

- … So what happens if the math isn't right??

Aliasing

- (B): TR=500ms, TE=2.5ms, FA=90^{o}, FOV=24cm, 10mm slice, N=200, N_{shot}=32, $\Delta\upsilon$=±62.5kHz, T_{acq}=8.129ms, SR=120 T/m/s, G_0=12.2mT/m, λ=0.21/cm
- (C): λ=0.38/cm, T_{acq}=4.8ms
- (D): G_0=22 mT/m, T_{acq}=4.8ms

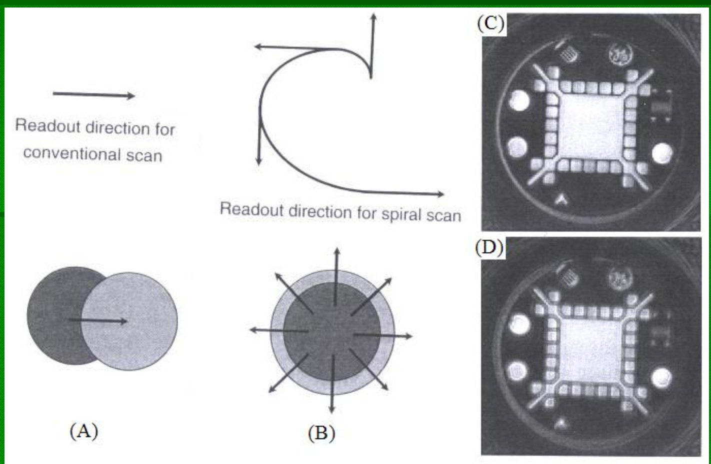


(A) The trajectory (B) The image (C) Radial aliasing (D) Azimuthal aliasing

Off-Resonance Blur

- Blurring, due to off-resonance effects, increases with T_{acq}
- Approaches to reduce blurring
  - *(a)* Decrease FOV: Introduces aliasing
  - *(b)* Increase N_{shot}: Increases scan time
  - *(c)* Increase Δx: Decreases spatial resolution

Blur



Dealing with Image Blur

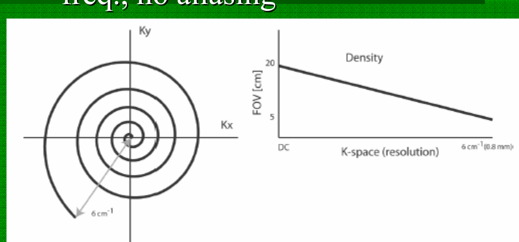
- Deconvolution
- Frequency-segmented correction
- Time-segmented correction
- Simulated phase-evolution rewinding (SPHERE)
- Block regional off-resonance correction (BRORC)

Variations of Spiral-Out Sampling

- Variable-density spirals with

(a) Undersampling of edges: Samples the center with Nyquist freq., time-efficient

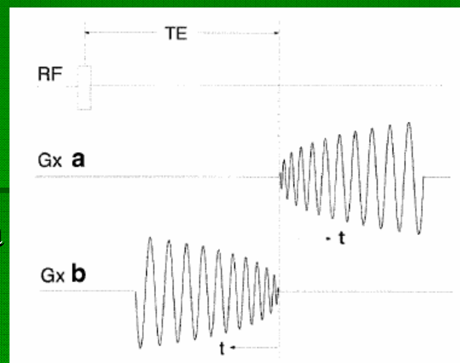
(b) Oversampling of k-space: Samples the edges at Nyquist freq., no aliasing



Source: Santos, 2006

Variations (Contd.)

- Reversed Spiral (Spiral-In) and Spiral-In/Out trajectories
- Spiral-In/Out is a Spiral-In followed by a conventional Spiral-Out readout

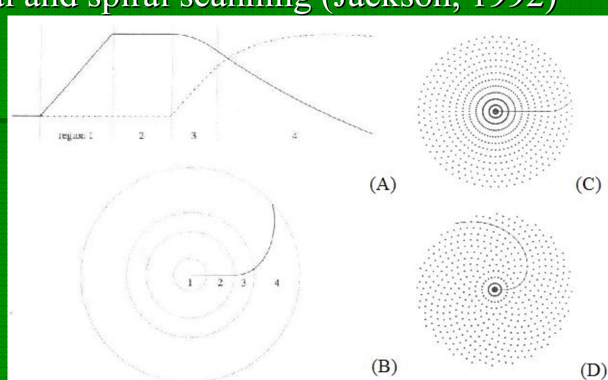


(A) Spiral-Out and (B) Spiral-In trajectories

Source: Glover, 2001

Variations (Contd.)

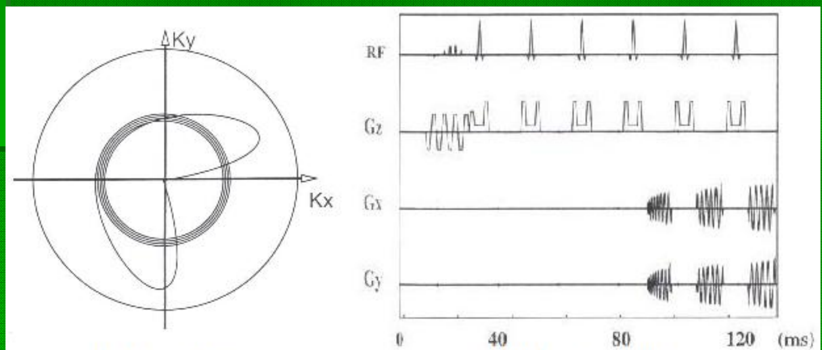
- Twisting Radial Line (TWIRL): a combination of radial and spiral scanning (Jackson, 1992)



(A) Gradient waveforms corresponding to (B). (C) and (D) are trajectories with different coverages of radial lines in k-space.

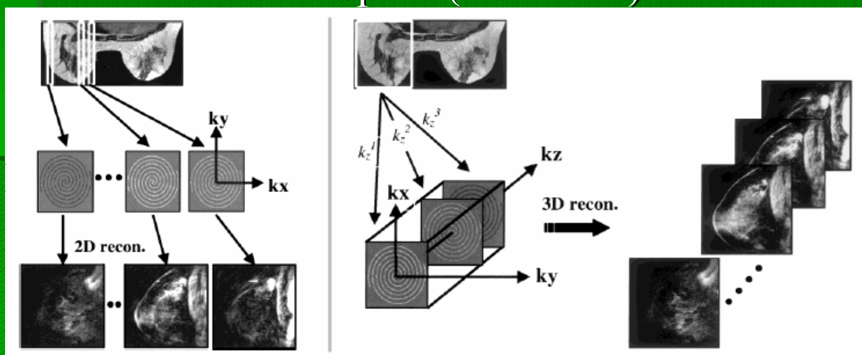
Variations (Contd.)

- RARE + Spiral (Block, 1997)



Variations (Contd.)

- 3-Dimensional Spiral (Yen 2000)



2-D versus 3-D spiral acquisition and reconstruction

Hardware Considerations

- Eddy currents are compensated for by adjusting the location of the A/D window relative to the spiral readout gradient
- Some gradient amplifier designs give poorer fidelity for spiral waveforms → blurring, shading or rotating of images

Comparison with Rectilinear Sampling

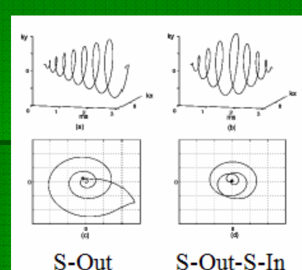
- Over-samples the center of k-space, so it is fairly motion insensitive
- Less number of shots required, therefore time-efficient
- Can be used with other techniques in MR

Comparison with Rectilinear Sampling (Contd.)

- Image Blurring due to off-resonance effects
- Aliasing from objects extending outside the FOV
- Longer reconstruction time
- Generally restricted to applications with small FOVs, where the effects of blurring are comparatively less

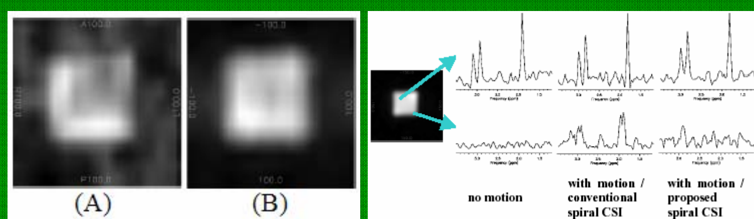
Spiral In-Out Scanning in CSI (Kim, 2003)

- Used spiral-out-in trajectory over conventional spiral-out, to reduce phase accumulated due to gradient moments
- Motion similar to respiratory movement was induced
- TR=1500ms, TE=144ms, 30cm FOV with 10cm PRESS box, 32x32 matrix, 0.5s readout with 2min scan time, motion was 1cm/sec in Y-direction.



Spiral In-Out Scanning in CSI (Kim, 2003)

- Spiral-Out Spiral-In trajectory is more efficient than cartesian phase encoding as well as conventional spiral scan to reduce motion effects in CSI.



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