TOPICS

- **2D Acquisition**
- **3D Acquisition**

2D Acquisition

Involves two main steps :

- **Slice Selection**

Slice selection is accomplished by spatially saturating (single or multi slice imaging) or canceling signals outside the slice of interest (single slice imaging), unless TR>>T1, to allow longitudinal magnetization to substantially recover to equilibrium.

- **Spatial encoding**

RF spin echo, gradient echo, EPI, projection acquisition or spiral acquisition could be used for sampling the k-space.

2D images are further produced using 2D fourier transform, gridding or filtered back projection of the k-space data.

2D Acquisition

To cover an imaging volume with 2D acquisition, multiple sections or slices must be acquired. Spatial information of each slice location is individually encoded into the k-space data matrix.

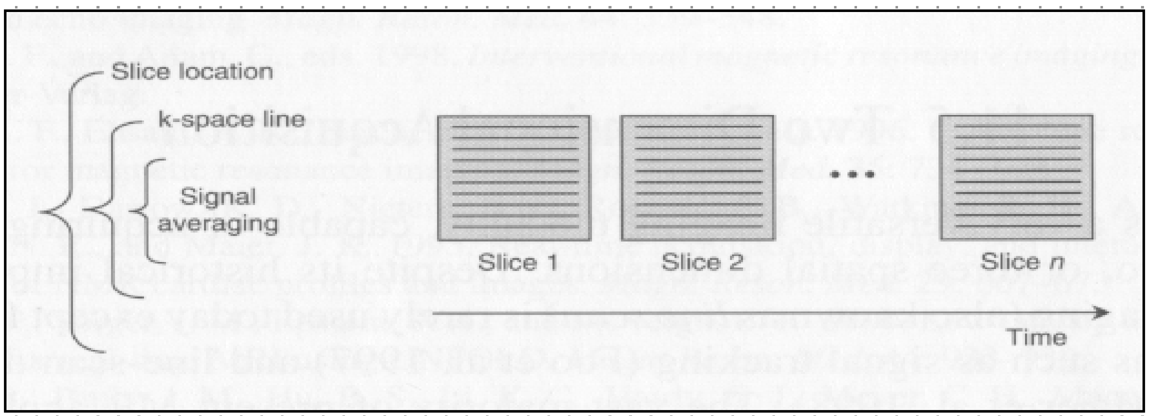
Sequential Acquisition

Acquiring all the required k-space lines for a given slice before moving to the next slice.

Signal averaging is done before moving to the next k-space line.

Order of acquisition is :

1) Signal Averaging
2) K-space lines
3) Slice Location



2D Acquisition

In sequential acquisition, magnetization is repeatedly excited every TR. If TR is longer than pulse sequence waveforms (T_{seq}), the scanner becomes inactive for TR-T_{seq}, termed as *idle time or dead time*.

Data acquisition efficiency = scanner-active time / total scan time.

Then the longer TR is relative to T_{seq}, the smaller the data acquisiton efficiency.

If T_{seq}=TR then efficiency is quite high.

Hence in practice sequential acquisition is used only if **T_{seq}=TR**

$T_{\text{K-space data}} = TR \times N_{phase} \times N_{EX}$ for one phase-encoding each pulse sequence
$T_{\text{K-space data}} = TR \times N_{phase} \times N_{EX} / N_{etl}$ for echo train pulse sequence

Used generally for time-of-flight angiography. Suppresses motion artifacts slower than $T_{\text{K-space data}}$

2D Acquisition

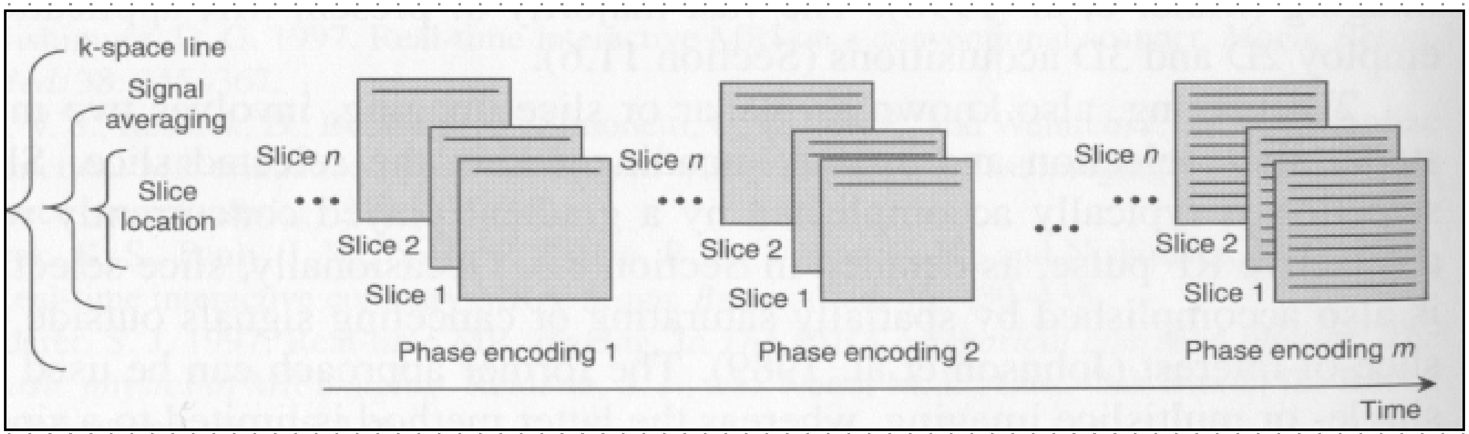
Interleaved Acquisition

Acquiring a specific k-space line for multiple slice locations and then repeating it for next line during the next TR interval.

Signal averaging is done before moving to the next k-space line.

Order of acquisition is :

1) Slice location
2) Signal Averaging
3) K-space lines



2D Acquisition

In interleaved acquisition, data for multiple slice locations can be acquired with each TR. Each sequence produces a k-space line at a different slice location.

Hence ‘idle time’ is used to acquire k-space data at other slice locations.

Max number of slices is given by,

$$N_{slice,acq}=\mathrm{int}(TR/T_{seq})$$

$$T_{scan} = TR \times N_{phase} \times N_{EX} \;\; ; \text{ if } \; N_{slice}<N_{slice,acq}$$

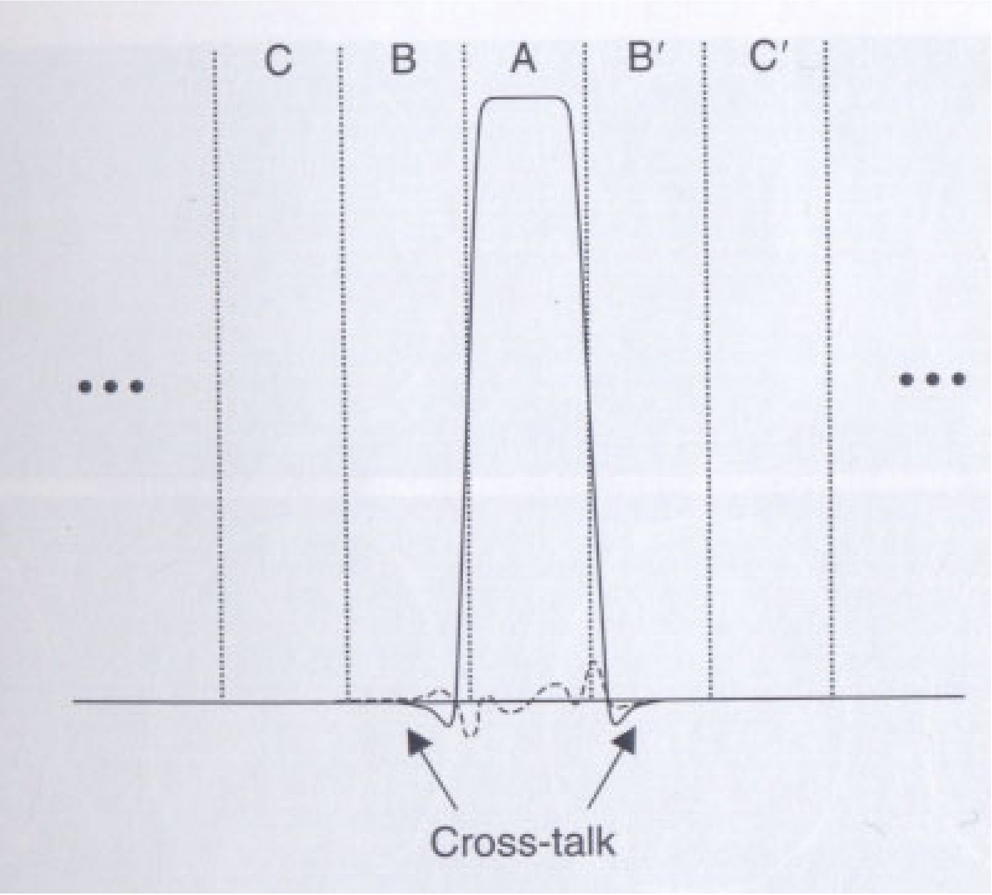
$$T_{scan} = TR \times N_{phase} \times N_{EX} \times N_{acq} \;\; ; \text{ if } N_{slice}>N_{slice,acq}$$

2D Acquisition

Cross Talk

When an RF pulse is applied to a desired slice location, the regions adjacent to the slice are inevitably affected. Magnetization of adjacent regions can be partially excited or inverted.

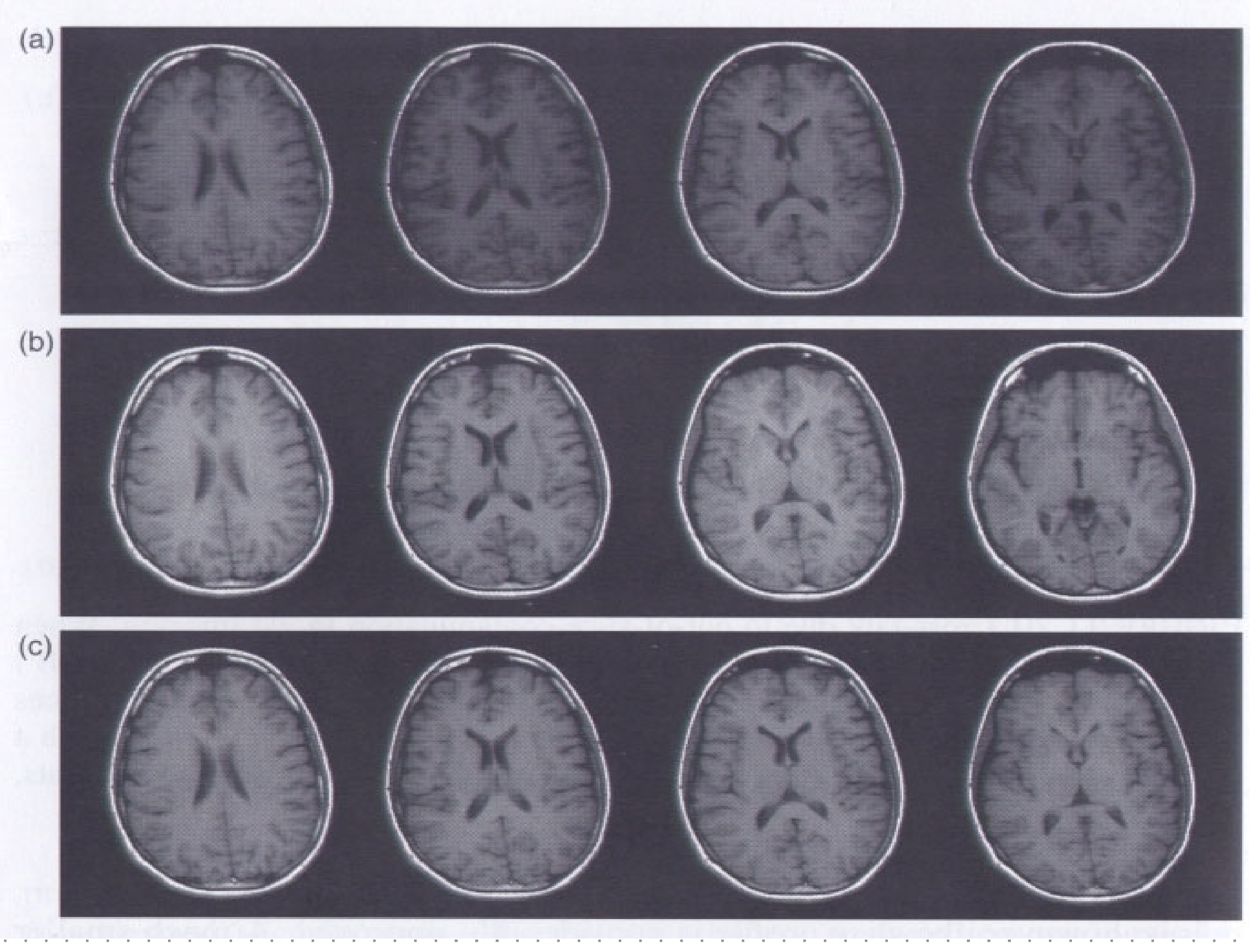
When those locations are imaged in subsequent acquisitions, decreased image intensity and altered contrast cause *slice cross talk.*



2D Acquisition

This cross talk can be reduced by using spatial gaps in between adjacent slices. These gaps serve as buffer against cross-talk which are not imaged.

But this can cause discontinuity along slice selection and also causes poor image quality. Although the gaps are very small could also cause loss of vital data.



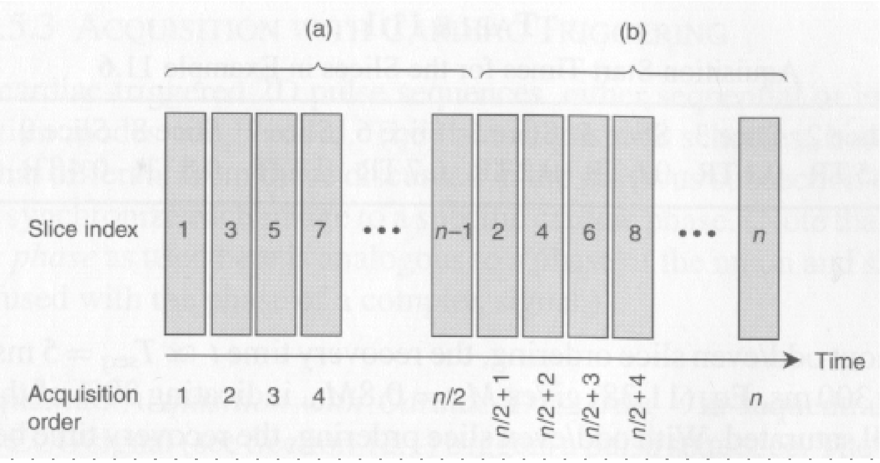
2D Acquisition

Another approach which is more effective is creating a *slice acquisition order.*

After acquiring k-space data for a given slice instead of acquiring data for its immediately adjacent slice we acquire data for a slice next adjacent slice.

Thus we first acquire data for all odd slices and then revert back to acquire data for the even slices.

This is often referred to as *odd/even slice acquisition order OR interleaved slice acquisition order.* **NOT INTERLEAVED ACQUISITION**



2D Acquisition

Odd/even slice acquisition depends on the rapid spatial decay of out-of-slice interference and efficient temporal recovery of the purturbed magnetization through T1-relaxation.

Without odd/even acquisition the magnetization outside the slice has a short time for T1-relaxation. $\approx T_{seq}$

The magnetizaton recovery time in odd/even acquisition is increased to :

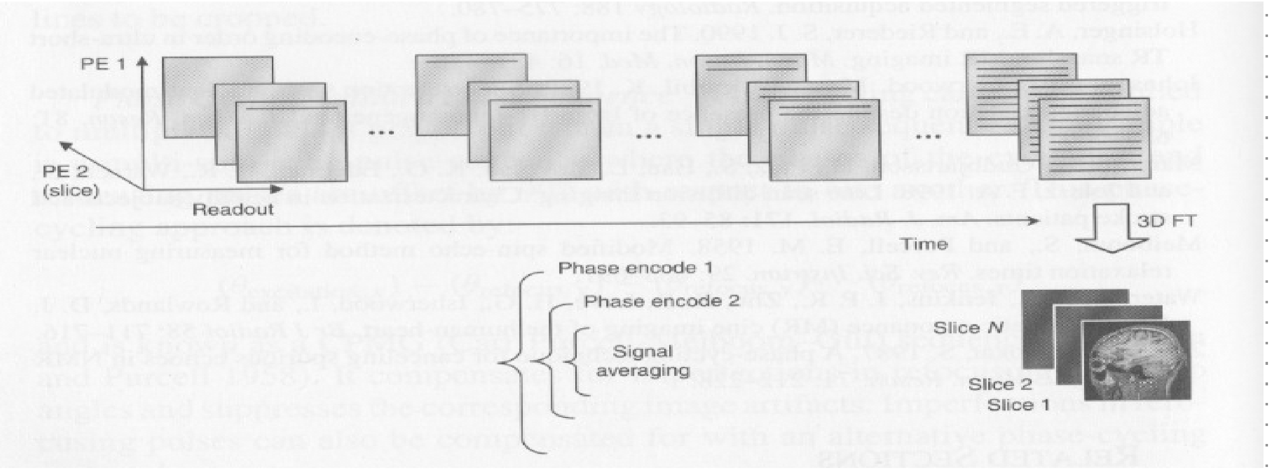
$$\approx \frac{N_{slice} * N_{phase} * N_{EX} * TR}{2}$$

3D Acquisition

Here an entire set of slices is simultaneously excited in each TR interval. The set of slices is called a chunk or a slab, and an individual element within the slab is called a partition, section or a slice.

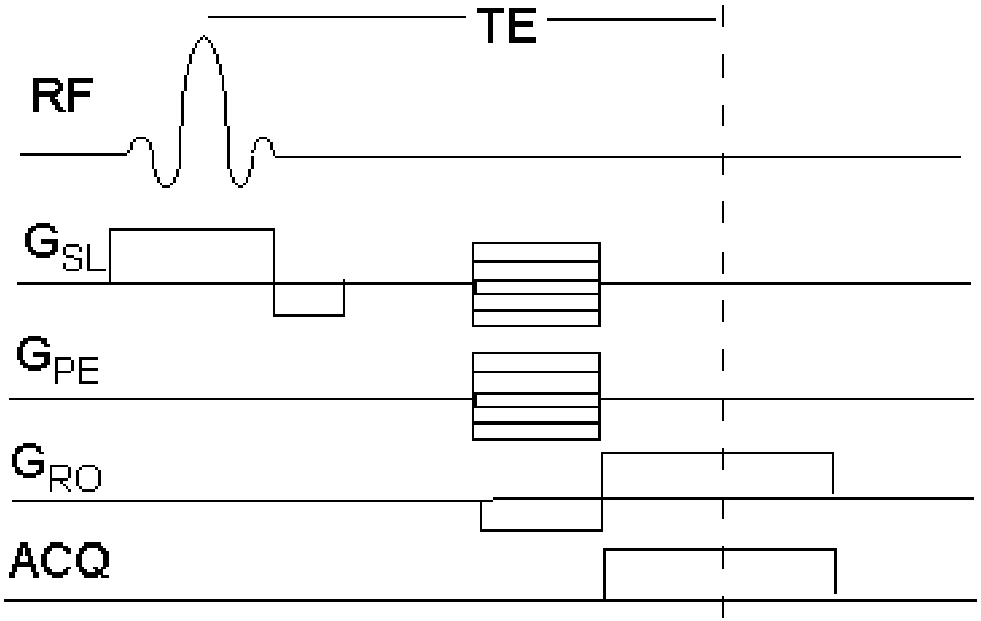
Most 3D MR use rectilinear sampling. Here the 3D volume is spatially encoded with phase encoding along two perpendicular spatial directions and frequency encoding along the third. Secondary phase encoding is called *phase encoding 2* or *slice encoding*.

Resultant data fills up a 3D k-space matrix, reconstructed by a 3D fourier transform.



3D Acquisition

- no slice selection gradient
- entire volume of tissue is excited
- second phase encoding gradient replaces the slice select gradient
- after the initial RF pulse, both Y and Z gradients are applied, followed by application of the X gradient during readout
- the Z gradient is changed only after all of the Y gradient phase encodes have generated an echo, then the z gradient is stepped and the Y gradient phase encodes are repeated.



Total acquisition time = $TR \times N_{PE} \times N_{SL} \times N_{EX}$.

Reconstruct image by 3D FT.

3D Acquisition

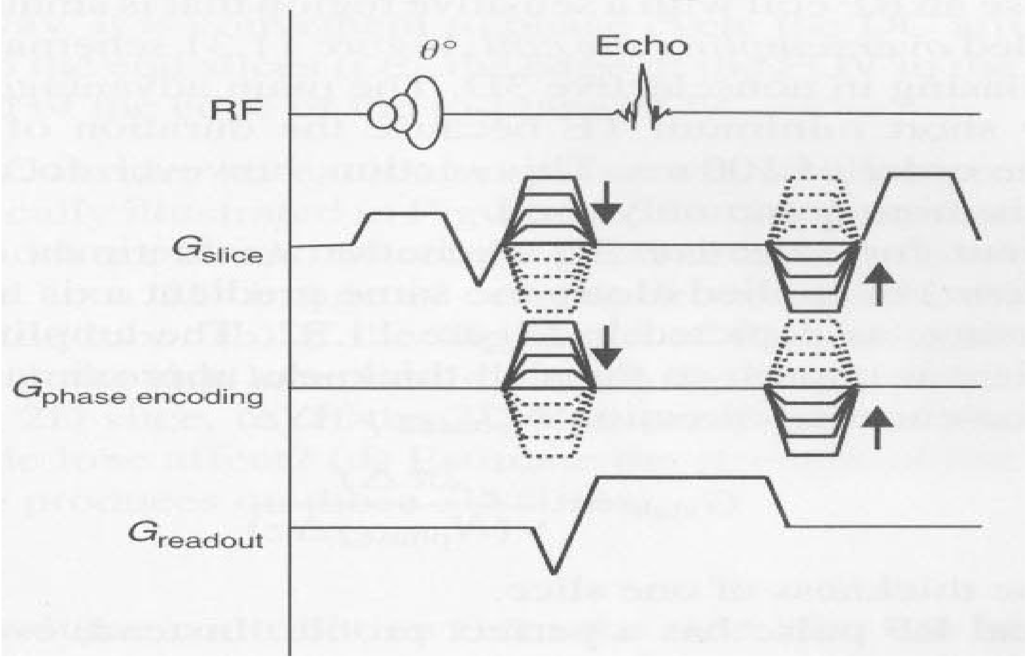
ADVANTAGES	DISADVANTAGES
• True contiguous slices	• Gradient echo imaging only
• Very thin slices (<1 mm)	• Motion sensitive
• No partial volume effects	
• Volume data acquisition	

3D Acquisition

Most 3D pulse sequences use selective RF excitation in order to limit aliasing artifacts in the slice encoded direction. This is called a **Selective 3D acquisition.**

The gradient for selective 3D excitation is given by :

$$G_{slab} = \frac{2\pi\Delta f}{\gamma(N_{phase2}\Delta z)}$$



3D Acquisition

Alternatively, non-selective 3D uses a hard pulse or a spectrally selective pulse for excitation. However it is highly prone to generate aliasing effect.

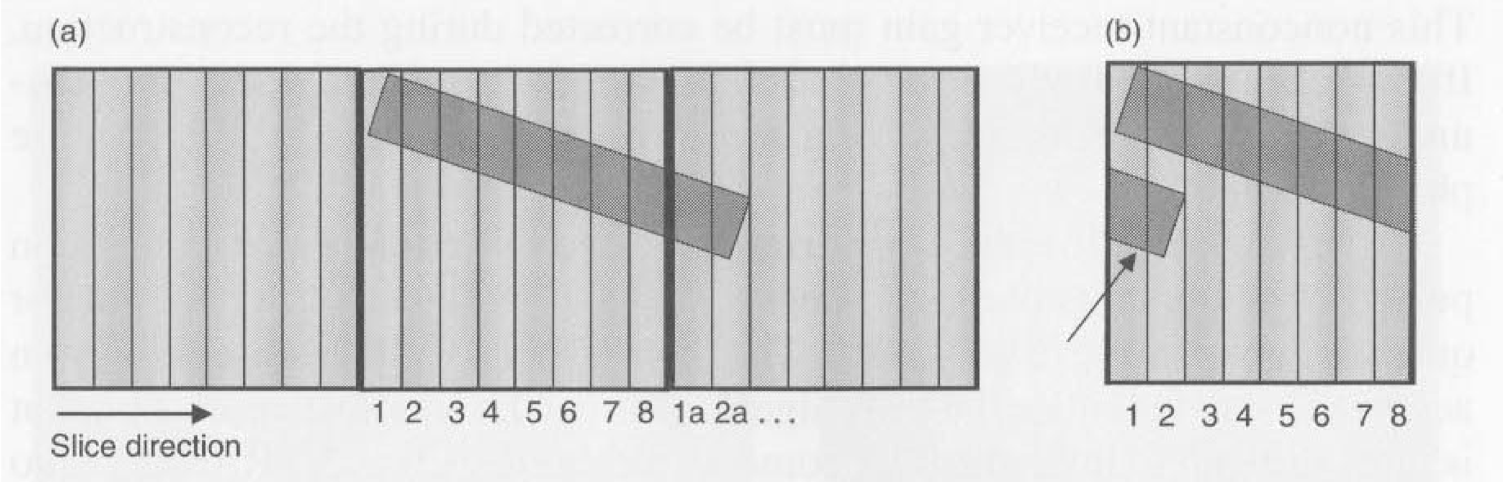
To limit aliasing, the user of non-selective 3D must either

- **Perform object over-sampling**
  Select a field of view in both phase encoding directions that is larger than the object

- **Perform coil over-sampling**
  Use an RF coil with a sensitive region that is smaller than the FOV.

The main advantage of nonselective 3D is its very short minimum TE because of the short duration of TE.

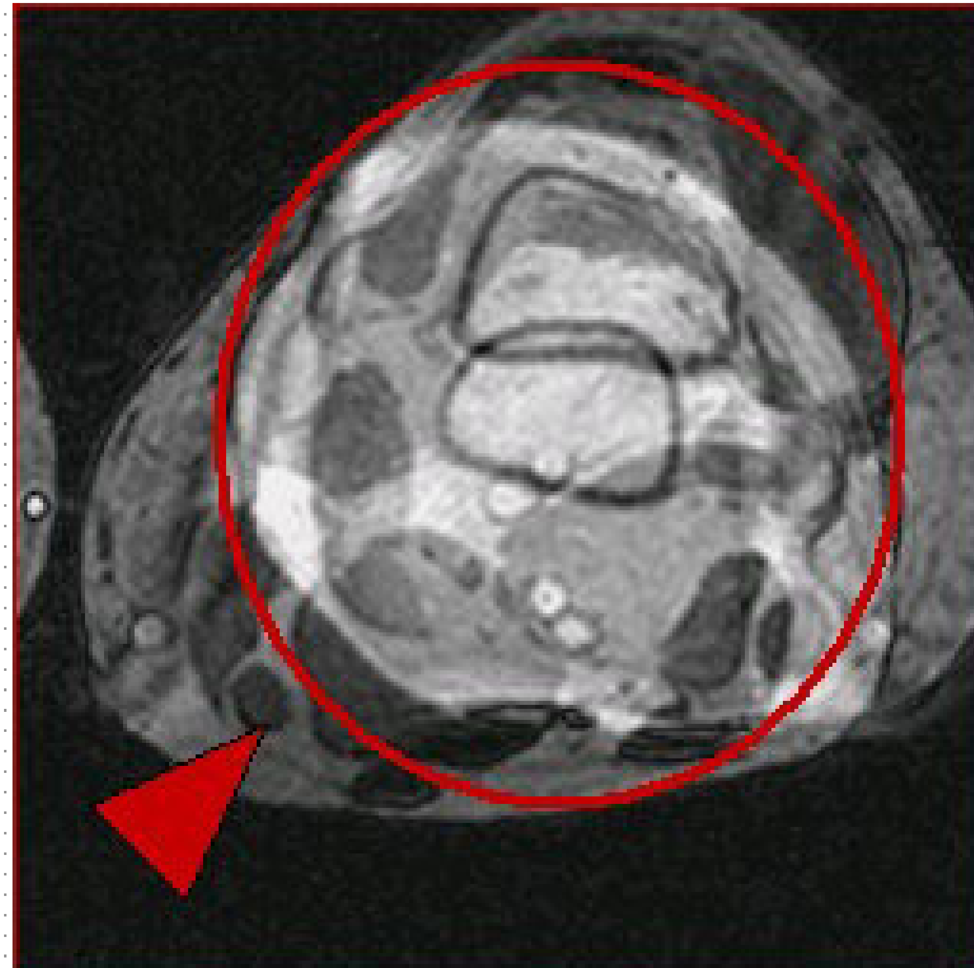
3D Acquisition



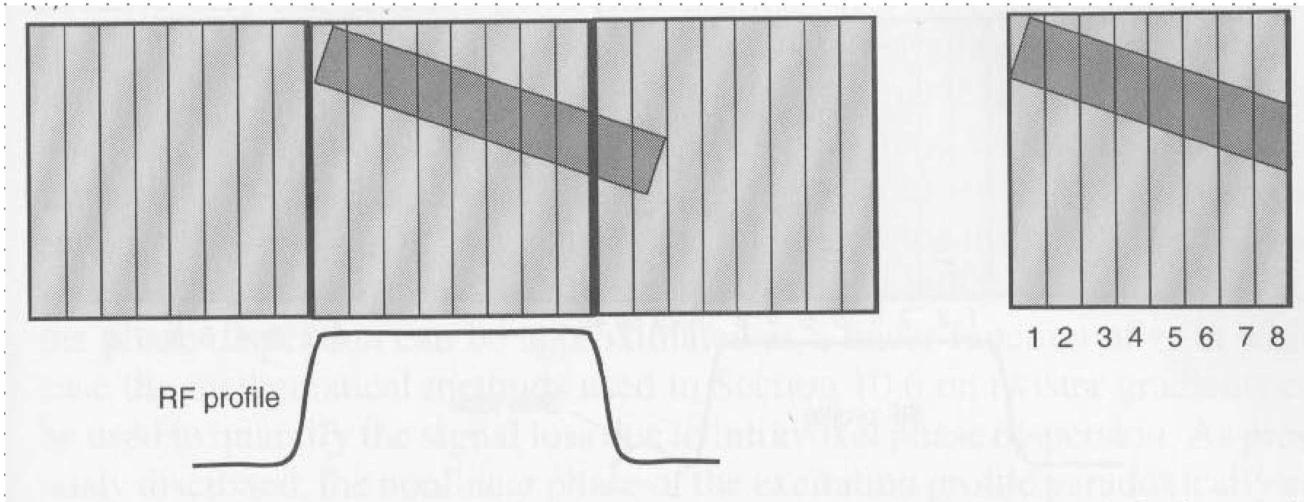
In non-selective 3D imaging, wrap around or aliasing artifact in each slice encoded direction can result if the object is bigger than the FOV

3D Acquisition

This case study shows a 3D acquisition technique with aliasing (in the red circle) in the slice selection direction. The image of the upper leg wraps into the image of the lower leg. Using the phase encoding gradient for two directions causes this artifact.



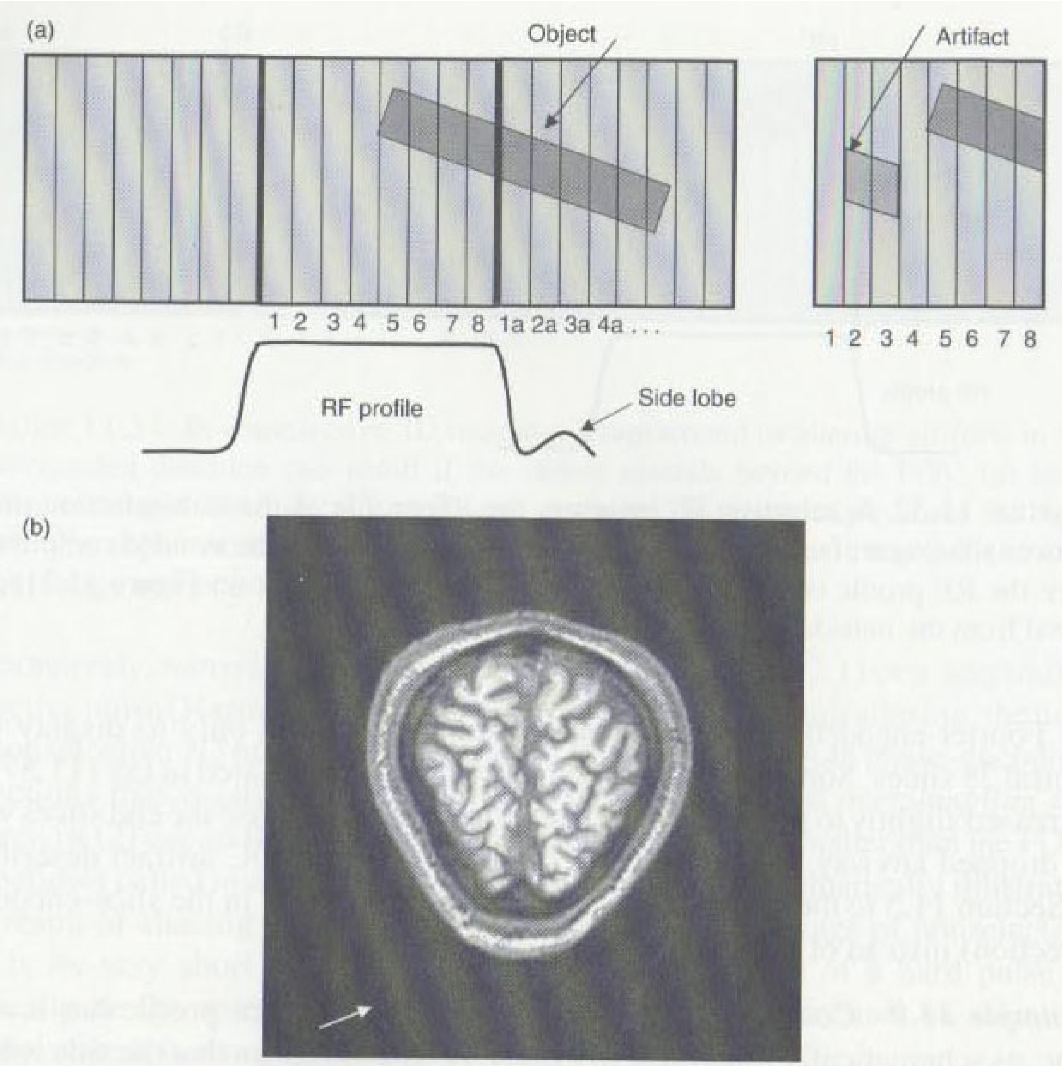
3D Acquisition



In selective 3D imaging depending on the RF pulse the slab selection can help reduce aliasing artifacts.

If the RF profile is ideal, aliasing can be avoided completely.

3D Acquisition



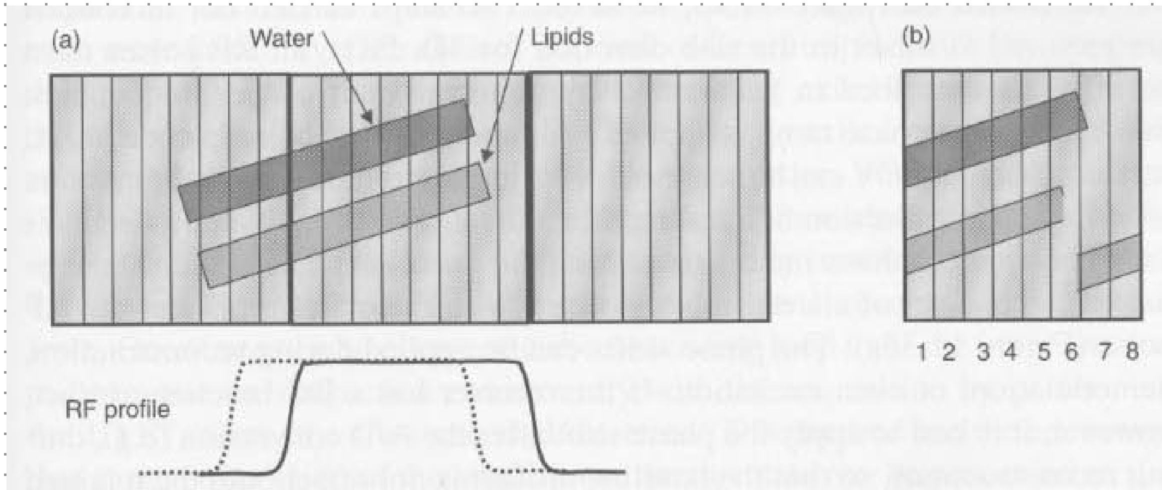
However, no practical RF pulse has a perfect profile.

Most profiles have a non-zero transition width between the stop band and the pass band. Ripples and a side lobe are not uncommon.

These can cause aliasing effect.

3D Acquisition

Chemical shift in the slice encoding direction displaces the profile of the selective excitation pulse, but does not offset the slice-encoded replicates.



The central slices in the slab are not affected, although naturally they are also prone to the standard chemical shift artifact in the frequency-encoded direction. Effective ways to counteract chemical shift in the slice direction in 3D include increasing the RF bandwidth of the slab-selection pulse and discarding the end slices.

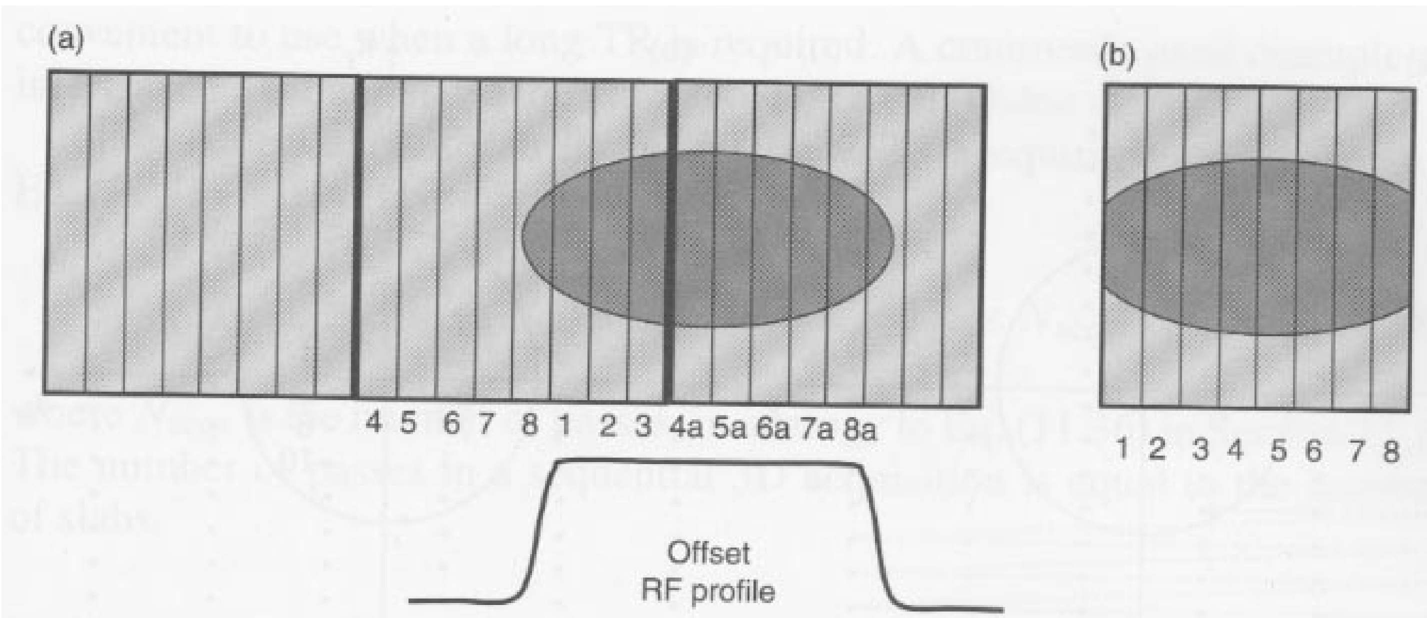
3D Acquisition

Here, the chemical shift artifact is visible as a small dark or bright border at the interfaces of bone, fat and muscle, best seen in the upper part of the head. This scan is taken with maximum water fat shift.

3D Acquisition

Offset slabs can be generated if

1) All RF pulses are offset.
2) A linear phase ramp is applied as a function of the slice encoded index, just as off-center FOV can be achieved.

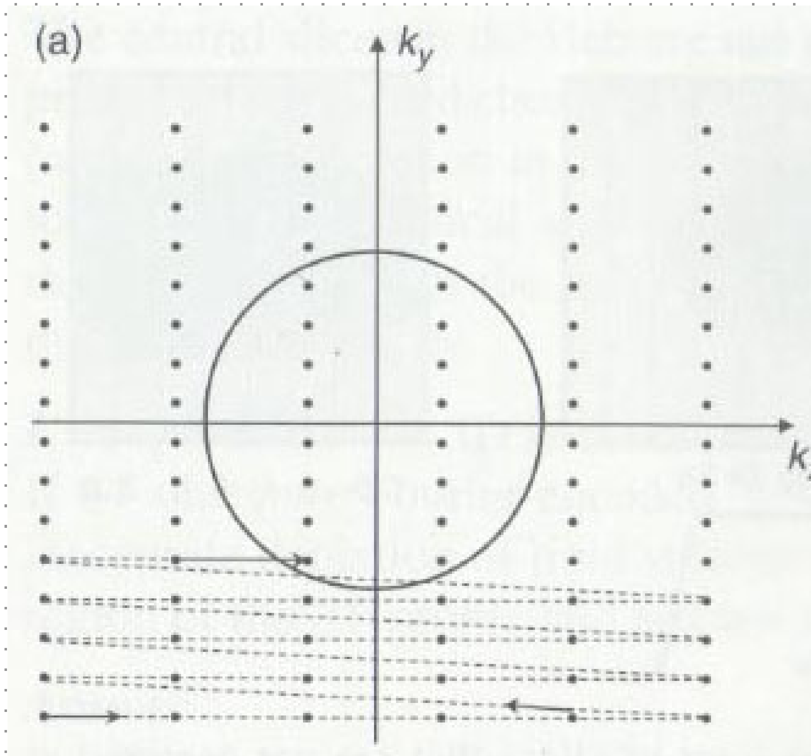


3D Acquisition

View Orders

Stepping through each of the values on one phase encoding axis before incrementing the value on the other phase-encoding axis, which is called *nesting* the phase encoding loops.Sequential, centric, reverse centric are a few view orders.

In sequential method at the completion of the acquisition. The raw data can be processed as if it were a set of multiple 2D slices.



With sequential view order the center of the k-space is acquired approximately halfway through.

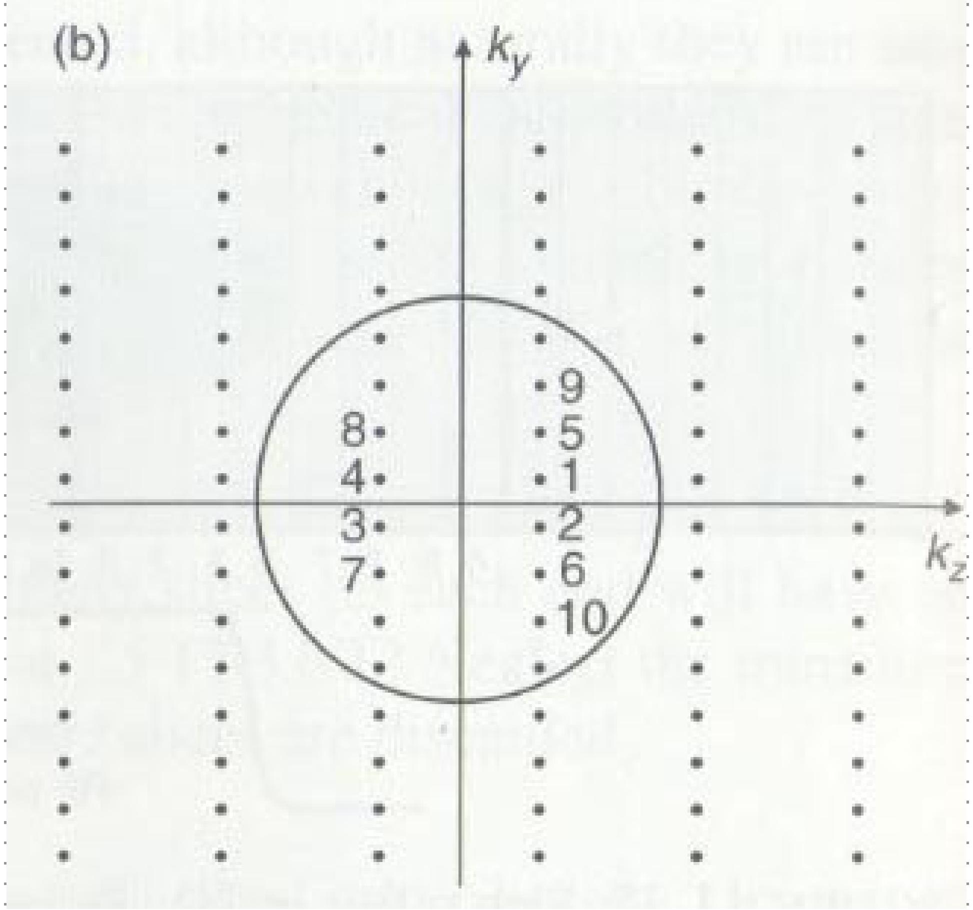
3D Acquisition

Elliptical centric view order and methods like CENTRA (Contrast Enhanced Timing Robust Angiography) replace two nested loops wit a single loop.

Acquisition starts at the center and ends towards the borders.

Here its distance to origin in the ky-kz plane determines the order of that particular view.

In reverse elliptical centric view order the view order is reversed to start the acquisition at the periphery and ends at the center.



3D Acquisition

Multi-slab or **Multiple Chunk 3D Acquisition**

Convenient to use when a long TR is required .

Often used in 3D RARE

In this case the T-scan is given by :

$$T_{scan} = TR \times N_{phase1} \times N_{phase2} \times N_{EX} \times N_{acq}$$

Comparison between 2D and 3D

Acquisition Time

Acquisiton time in 3D scans increases or decreases ? Why ?

Comparison between 2D and 3D

Minimum Slice Thickness

Why are thin slices required ?

The slice thickness in 2D is given by $\boxed{\Delta z_{2D} = \frac{2\pi\Delta f}{\gamma G}}$

The slice or partition thickness for a 3D acquisition is inversely proportional to the area under the largest phase-encoding lobe.

$$\Delta z_{3D} = \frac{1}{N_{phase2}\Delta k_z}$$

The conversion of step sixe in k-space in terms of gradient is given by $\Delta A = \frac{2\pi\Delta k}{\gamma}$

Slice encoding ranging from $+A_{max}$ to $-A_{max}$ in N_{phase2} steps. Hence $\Delta A = \frac{2A_{\max}}{N_{phase2}-1}$

$$\boxed{\Delta z_{3D} = \frac{(N_{phase2}-1)\pi}{\gamma N_{phase2} A_{\max}}}$$

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