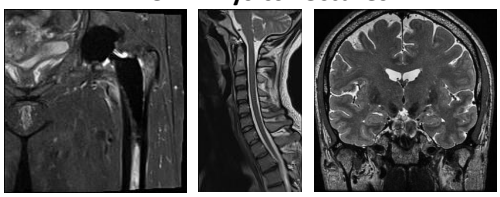
Magnetic Resonance Imaging

F.R.C.R. Physics Lectures



Lawrence Kenning PhD

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Magnetic Resonance Imaging

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FRCR MRI Syllabus

Magnetic Resonance Imaging (MRI) [1]

- Multi-echo, fast spin-echo and single shot techniques
- SNR Factors

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Multi-echo, fast spin-echo and single shot techniques

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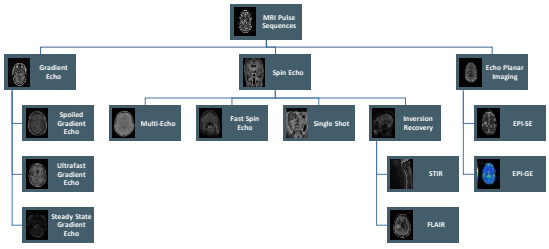
MRI Pulse Sequences



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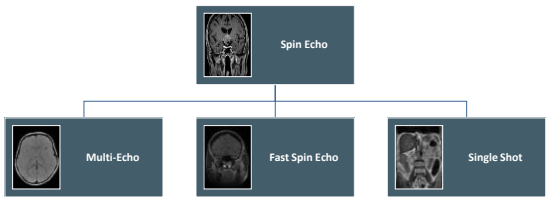
Multi-echo, fast spin-echo and single shot techniques



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Multi-echo, fast spin-echo and single shot techniques

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Multi-Echo Sequences

- Allow several images of the same slice position without increasing overall acquisition time
- Images obtained with different contrast
- After first echo is obtained, free interval until next TR
- By applying a new 180° pulse a new echo is received (but with the "same" phase encoding)
- The echo time of the 2 images differs and the second image will be more T_2 weighted than the first
- Typically used to obtain simultaneously P.D. & T_2-weighted images

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Multi-echo, fast spin-echo and single shot techniques

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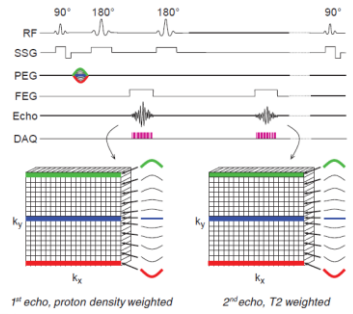

1st echo, proton density weighted 2nd echo, T2 weighted

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Multi-echo, fast spin-echo and single shot techniques

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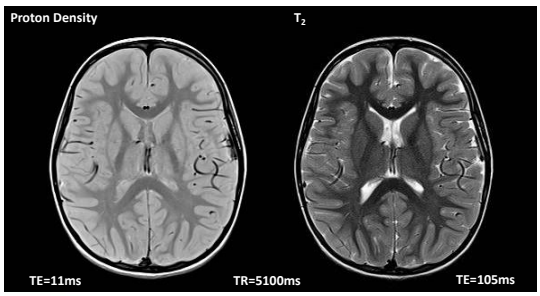

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Multi-echo, fast spin-echo and single shot techniques

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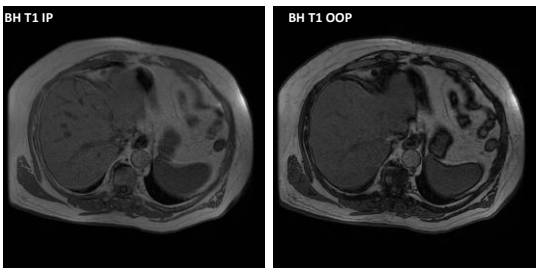

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Multi-echo, fast spin-echo and single shot techniques

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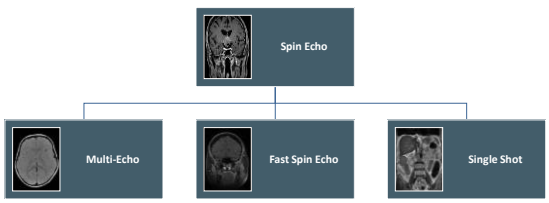

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Multi-echo, fast spin-echo and single shot techniques

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Fast Spin Echo (FSE) / Turbo Spin Echo (TSE)

- Interval time after the first echo used to retrieve echo train and fill other k-space lines.
- Done by applying new 180° pulses to obtain a spin echo "train".
- After each echo, the phase encoding is cancelled and a different phase encoding applied to the following echo
- Number of echoes received in the same repetition (TR) time is called the Turbo factor or Echo Train Length (ETL)
- Because of the reduced number of repetitions (TR), k-space is filled faster and slice acquisition time reduced.
- Time of scan = $(N_{PE} \times TR \times NEX)/ ETL$

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Multi-echo, fast spin-echo and single shot techniques

Echo Train Length (ETL)

- Longer ETLs result in greater T_2-weighting since more higher TE echoes will contribute to the final image contrast
- Longer ETL are also associated with a decrease in overall signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR)
- Scan time is given by:

$$N_{PE} \times TR \times NEX / ETL$$

- For a 256x256 image with a TR of 4000ms, 1 average and an echo train length of 24, the scan time would be 43 seconds
- The effective TE (TE_{eff}) describe the TE of central echo which fills the centre of k-space

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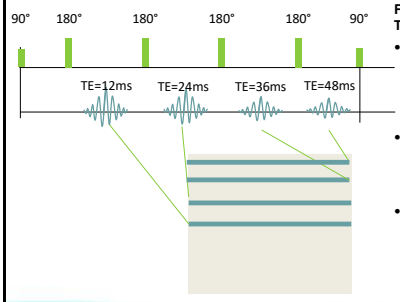
Multi-echo, fast spin-echo and single shot techniques



Fast Spin Echo (FSE) / Turbo Spin Echo (TSE)

- It is possible to utilise the interval time after the first echo to fill additional lines of k-space
- Achieved by applying additional 180° pulses to obtain a spin echo "train"
- Number of echoes received during the same repetition time (TR) is called the Turbo factor or Echo Train Length (ETL)

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Multi-echo, fast spin-echo and single shot techniques

Fast Spin Echo: Contrast, Resolution & Scan Time

- Contrast is modified compared to a standard SE sequence
- As echoes received at different echo time, echoes corresponding to central k-space are the ones determining image contrast
- Time at which these echoes are acquired is called effective TE
- TE_{eff} is arranged to coincide with the central parts of k space.
- FSE can be P.D., T_1 or T_2 weighted
  - In T_1 weighted sequences need to choose short TR: limits echo train length

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Multi-echo, fast spin-echo and single shot techniques

3D FSE/TSE

- SPACE/CUBE/3D BrainVIEW are 3D FSE/TSE sequences that utilise very long echo trains… up to 250 echoes long!
- Usually implement variable flip angles to limit SAR (sometimes constant)
- Ability to create T_1, T_2, P.D., FLAIR, STIR and DIR image contrasts
- Offer sub-millimetre imaging in clinical times (3-6 min)
- Possible replacement for multiple 2D acquisitions

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Multi-echo, fast spin-echo and single shot techniques



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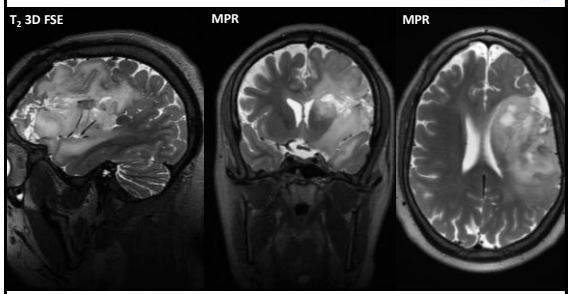
Multi-echo, fast spin-echo and single shot techniques



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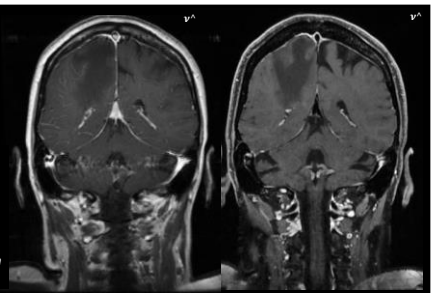
Multi-echo, fast spin-echo and single shot techniques

FSE

2D T_1 FSE +C
FOV = 24cm
Matrix = 384x224
Phase FOV = 0.8
TR/TE = 602/14.4
ARC = 2
SL Thick= 5/1mm
Scan Time = 1:53

3D T_1 FSE FS +C
FOV = 24cm
Matrix = 320x320
Phase FOV = 0.8
TR/TE = 602/14.4
ARC = 2 x 2
SL Thick= 0.6/0mm
Scan Time = 3:35



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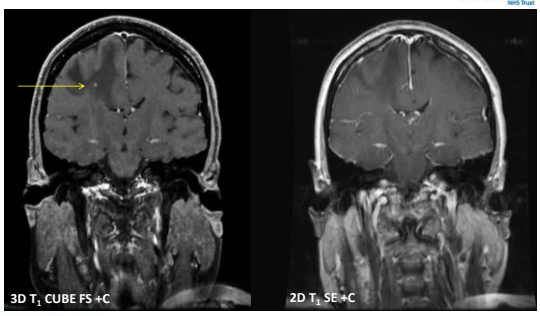
Multi-echo, fast spin-echo and single shot techniques



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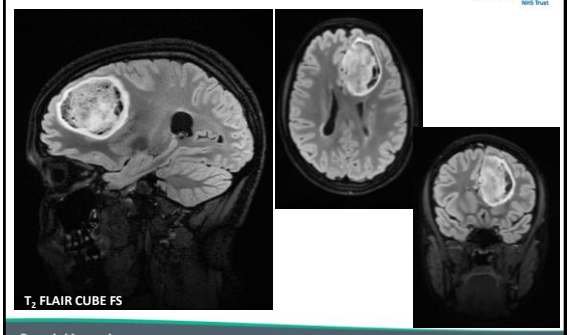
Multi-echo, fast spin-echo and single shot techniques



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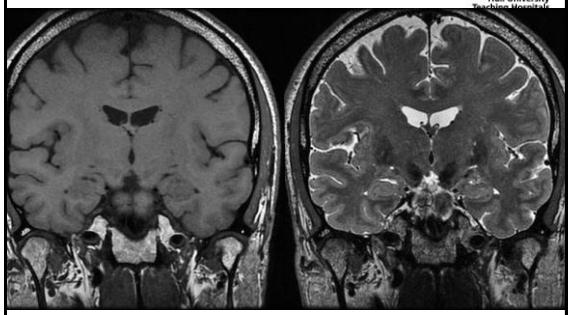
Multi-echo, fast spin-echo and single shot techniques



T1 3D FSE (CUBE) 0.5mm slice thickness

T_2 3D FSE (CUBE) 0.5mm slice thickness

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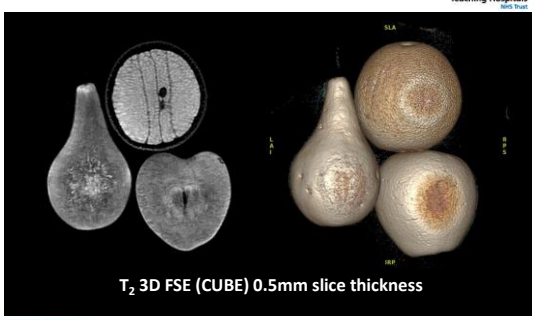
Multi-echo, fast spin-echo and single shot techniques



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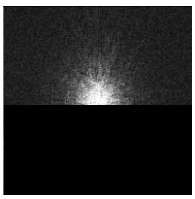
Multi-echo, fast spin-echo and single shot techniques

Ultrafast SE (Single Shot Technique)

- Echo Train Technique can be pushed to fill entire Fourier plane with a single 90° pulse (so TR is infinite)
- Requires successive application of as many 180° pulses as there are k-space lines to fill.
- Partial k-space acquisition can be used
- Just over half k-space lines acquired
- Missing lines calculated using k-space symmetry properties
- Reduces acquisition time, but to detriment of SNR



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Multi-echo, fast spin-echo and single shot techniques

Ultrafast SE (Single Shot Technique)

- Images are highly T_2 weighted as majority of k-space lines are filled with long TE echoes.
- Duration = TE * N_{PE}
- Well adapted to imaging non-circulating liquid structures appearing as highly T2 weighted signal: Cholangio MRI (gallbladder, biliary system and pancreas: MRCP); Uro-MRI
- Low sensitivity to movement
- Cons
  - Decay in SNR
  - Low spatial resolution and blurring in PE direction

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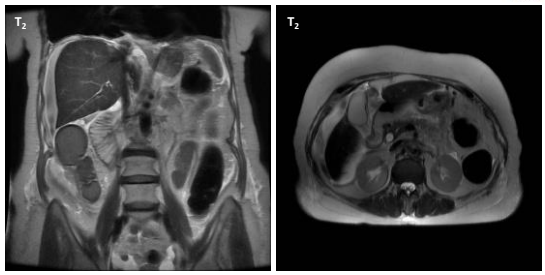
Multi-echo, fast spin-echo and single shot techniques



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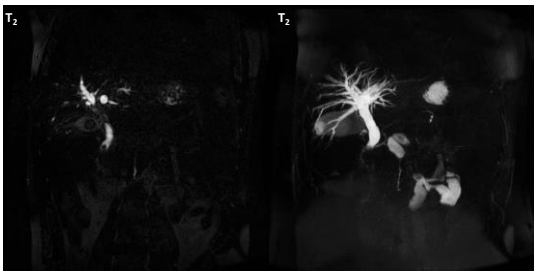
Multi-echo, fast spin-echo and single shot techniques



TE=520ms/TR=3000ms

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SNR Factors

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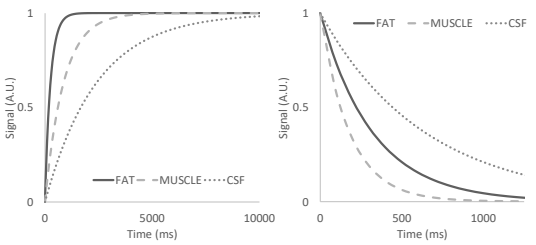
SNR

T_1 and T_2 Relaxation



- Increasing the TR will increase SNR
- Decreasing the TE will increase SNR

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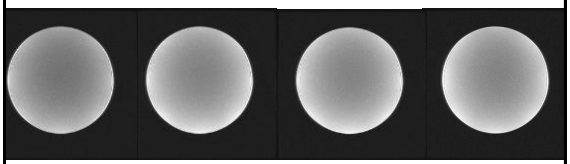
SNR



TR=500ms TR=1000ms TR=2000ms TR=3000ms

TR	SIGNAL	NOISE	SNR
500	317.65	5.74	55.3
1000	368.88	5.51	66.9
2000	373.19	5.92	63.0
3000	373.59	5.94	62.9

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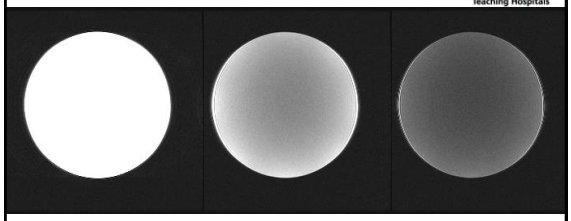
SNR



TE=50ms TE=100ms TE=150ms

TE	SIGNAL	NOISE	SNR
52.6	982.00	6.09	161.2
99.3	373.59	5.94	62.9
140.2	175.46	5.66	31.0

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SNR

Image Weighting

	Short TR	Long TR
Short TE	T_1 Weighted	P.D. Weighted
Long TE		T_2 Weighted

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SNR

Field of View (FOV)

- 256x256 Matrix. 5mm Slice Thickness
- 200mm x 200mm FOV = 200/256 = 0.78mm in-plane voxel size
- 250mm x 250mm FOV = 250/256 = 0.98mm in-plane voxel size
- $5x0.98^2 / 5x0.78^2 = 1.56$
- 200mm FOV => 250mm FOV = 56% increase in SNR
- Increasing FOV will boost SNR and decrease resolution but no time penalty

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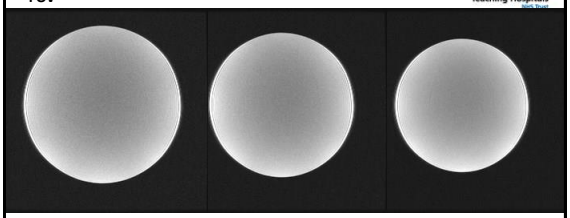
SNR

FOV



FOV=220mm FOV=240mm FOV=260mm

FOV	SIGNAL	NOISE	SNR
220	358	6.72	53.3
240	373	5.94	62.8
260	394	4.75	82.9

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SNR

Matrix Size

- 240mm FOV. 5mm Slice Thickness
- Increasing Matrix will decrease SNR and increase resolution

FOV	Matrix	SNR	In-Plane (mm)
240	*128*	17.58	1.88
240	*192*	7.81	1.25
240	*256*	4.39	0.94
240	*320*	2.81	0.75

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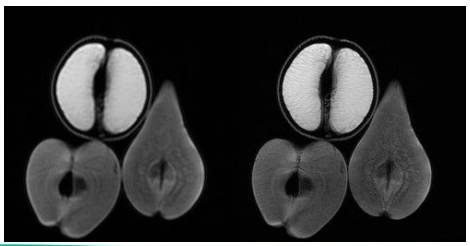
SNR

Matrix Size

- 240mm FOV. 5mm Slice Thickness
- Increasing Matrix will decrease SNR and increase resolution



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SNR

Slice Thickness (S.T.)

- SNR is proportional to Slice Thickness
- 2mm S.T. => 3mm S.T. = 50% increase in SNR
- Desire to avoid partial volume effects
- Increasing S.T. will boost SNR and decrease resolution with no time penalty
- 3D may be preferable when thin slices are desired

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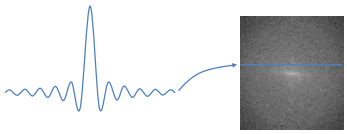
SNR

Bandwidth

- Decreasing the bandwidth increases the SNR
- Reducing the bandwidth reduces noise by the square root of the reduction



$$\text{receiver Bandwidth} = \frac{1}{\text{sampling time of echo}}$$

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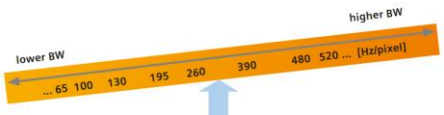
SNR

- higher SNR
- less noise
- smaller minimal FOV

+

- less chemical shift
- shorter min. TE/TR
- shorter echo spacing
- reduced susceptibility artifacts
- fewer metal artifacts



- more chemical shift
- longer min. TE/TR
- longer echo spacing
- increased susceptibility artifacts
- more metal artifacts

−

- lower SNR
- more noise
- larger minimal FOV

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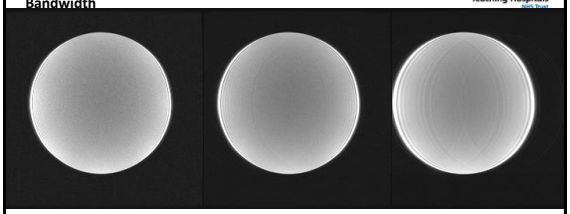
SNR

Bandwidth



BW=62.5kHZ BW=31.3kHZ BW=15.6kHZ

BW (kHz)	SIGNAL	NOISE	SNR
62.5	373	5.94	62.8
31.3	341.6	4.24	80.6
15.6	375.9	3.13	120.1

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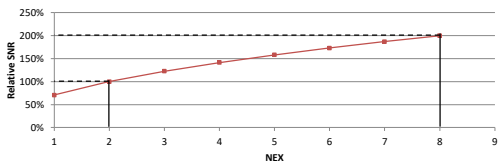
SNR

NEX/NSA

- Increasing NEX will increase SNR
- SNR increase is proportional to the square root of the NEX



- Relative SNR changes for a 2NEX Scan
- Scan 4 times longer to double the SNR

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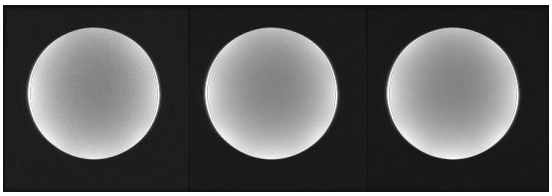
SNR

Number of experiments / number of signal averages (NEX/NSA)



1NEX 2NEX 4NEX

NEX	SIGNAL	NOISE	SNR
1	373.59	5.94	62.9
2	372.82	4.03	92.5
4	372.88	3.04	122.7

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SNR

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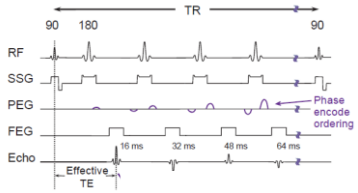
Echo Train Length (ETL)

- Longer ETLs result in more T2-weighting because more late echoes with longer TE's contribute to the overall signal.
- Longer ETL's are also associated with a decrease in overall signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) because the later echoes are weaker.



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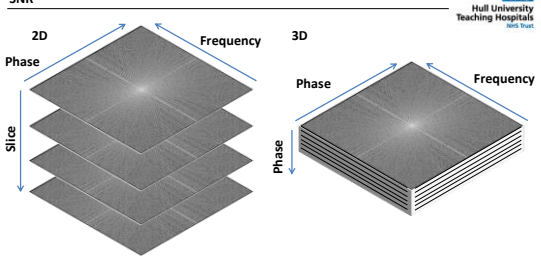

- For 3D, excitation of the complete volume for each repetition
- Excitation repeated for each phase encoding in the 3rd Dimension
- Additional phase encoding direction also adds wrap in 3rd Dimension

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SNR

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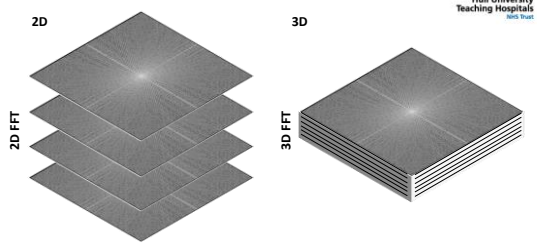

- Every point in K-space goes to every point in image space
- 2D x and y
- 3D x, y and z!

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SNR

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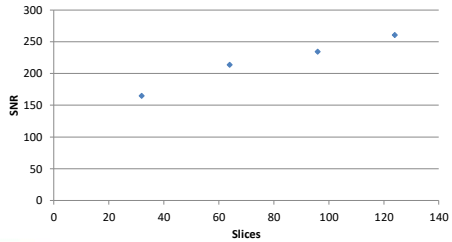
2D vs 3D

- For 3D sequences, SNR is proportional to the number of slices
- For 2D sequences, SNR is independent.



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Improving SNR

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$$SNR_{voxel} \propto \frac{(Voxel\ size) \times \sqrt{number\ of\ measurements}}{\sqrt{receiver\ bandwidth}}$$

SNR Improvement	Drawback
Increase voxel size -Increase FOV -Increase slice thickness -Decrease number of phase encoding steps	Decreases spatial resolution
Increase number of averages	Increases imaging time disproportionately
Use narrower bandwidth	Limits number of slices for a given TR and can also affect minimum TE

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Question

In magnetic resonance imaging the following are true:

A. Within a single TR, following collection of PD-weighted data the echo can be re-sampled after another TE to provide T_2-weighted data

B. Fast (turbo) spin-echo (FSE) techniques use several refocusing 180° RF pulses to rephase and produce extra echoes at different phase gradients for each excitation

C. SNR decreases as voxel volume increases

D. T_2 imaging always provides the best degree of tissue contrast

E. Spatial resolution is reduced when using a thinner slice

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Question

Signal to noise in MRI is increased with:

A. A decreased matrix size

B. A longer TE

C. A thicker slice

D. A smaller field of view

E. The use of a higher main magnetic field

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