

MRI Sequence Parameters and Protocols

Memorial Sloan Kettering Cancer Center

Jason Dursi, MBA, R.T.(T)(MR)

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Learning Objectives

Describe and discuss the 4 main considerations that determine image quality.

- SNR, CNR, spatial resolution, temporal resolution

Describe factors that affect scan time and understand how to calculate it.

Describe and discuss common imaging parameters and describe the effects on scan time and the 4 considerations above.

- TR
- TE
- TI
- Proton Density
- Flip angle
- Slice thickness
- Matrix
- FOV

Discuss Protocol selection for Radiation Oncology

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TR and TE

TE

- The time from the center of the 90 degree RF excitation pulse to the center of the echo is called the *echo time, or TE.*

TR

- The time from the application of one 90 degree excitation RF pulse, to the application of the next 90 degree excitation RF pulse, **applied to the same population of protons**, is called *repetition time, or TR*.

The TR and TE are ***extrinsic*** *contrast parameters* which can be varied to control the contrast between tissues.

TR and TE

TR is the parameter which controls how much contrast due to T1 relaxation is seen between tissues.

- As the TR is shortened, the T1 contrast improves.

TE is the parameter which controls how much contrast due to T2 relaxation is seen between the tissues.

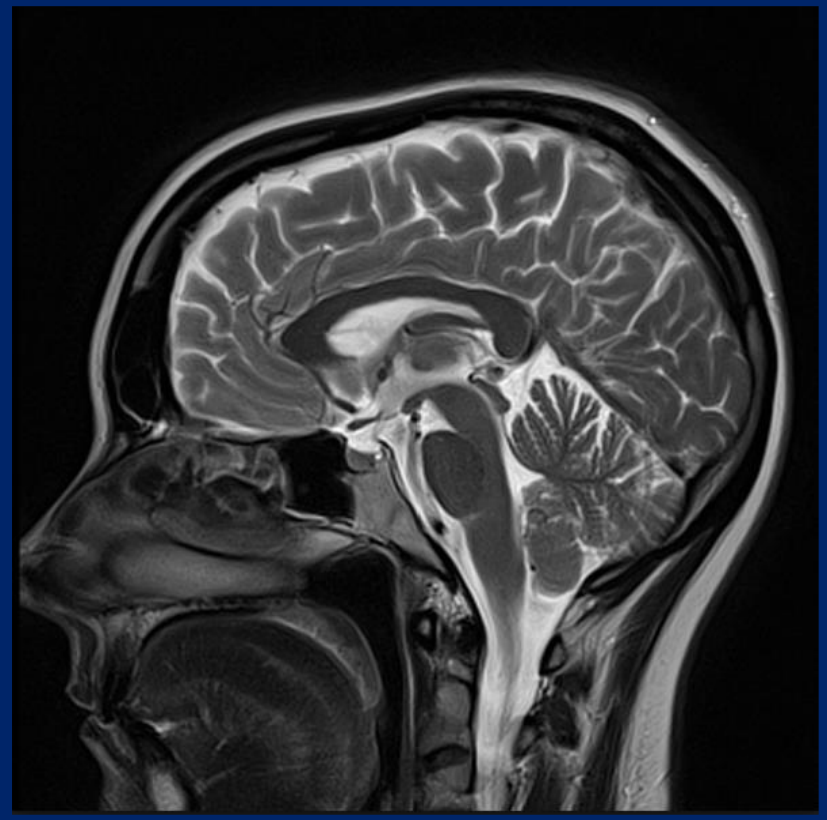
- As the TE is lengthened, the T2 contrast improves.

Image Contrast

Areas on MR images that are **bright** were created by a **strong** signal strength, while *dark* areas come from a *weak* signal strength.

To produce high signal, a large component of *coherent magnetization* must be near the transverse plane.

Low signal is produced when a small component of coherent magnetization lies in the transverse plane.



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Protocol

A protocol is a “set of rules”

In MRI, these rules consist of:

- Extrinsic contrast parameters
- Geometry parameters
- Imaging options
- Data acquisition methods
- Many of these are operator controlled!

A properly set-up protocol will demonstrate anatomy or pathology with diagnostic quality.

A poorly set-up protocol may produce images that are not diagnostic.

Imaging Parameters

Four main considerations for determining image quality:

- Signal-to-noise ratio (SNR)
- Contrast-to-noise ration (CNR)
- spatial resolution
- Temporal Resolution - Scan time

Imaging Parameters

Ideal image set would have:

- High SNR
- Excellent CNR
- High spatial resolution
- Short scan time

Due to limitations in MR, this ideal set will not happen.

- Image quality needs to be “good enough”
- This occurs through the use ofoptimized imaging parameters
- Trade-offs must be made.

Imaging Parameters

- The proper selection of operator-controlled parameters is extremely important.
  - A quality MR technologist must always be thinking about scan time when he or she is making any changes to the imaging parameters
  - A quality MR technologist will know that a change in one parameter will affect many other parameters as well.
  - Before making a change in any parameters, it is very important to understand how the image quality and scan time will be influenced.

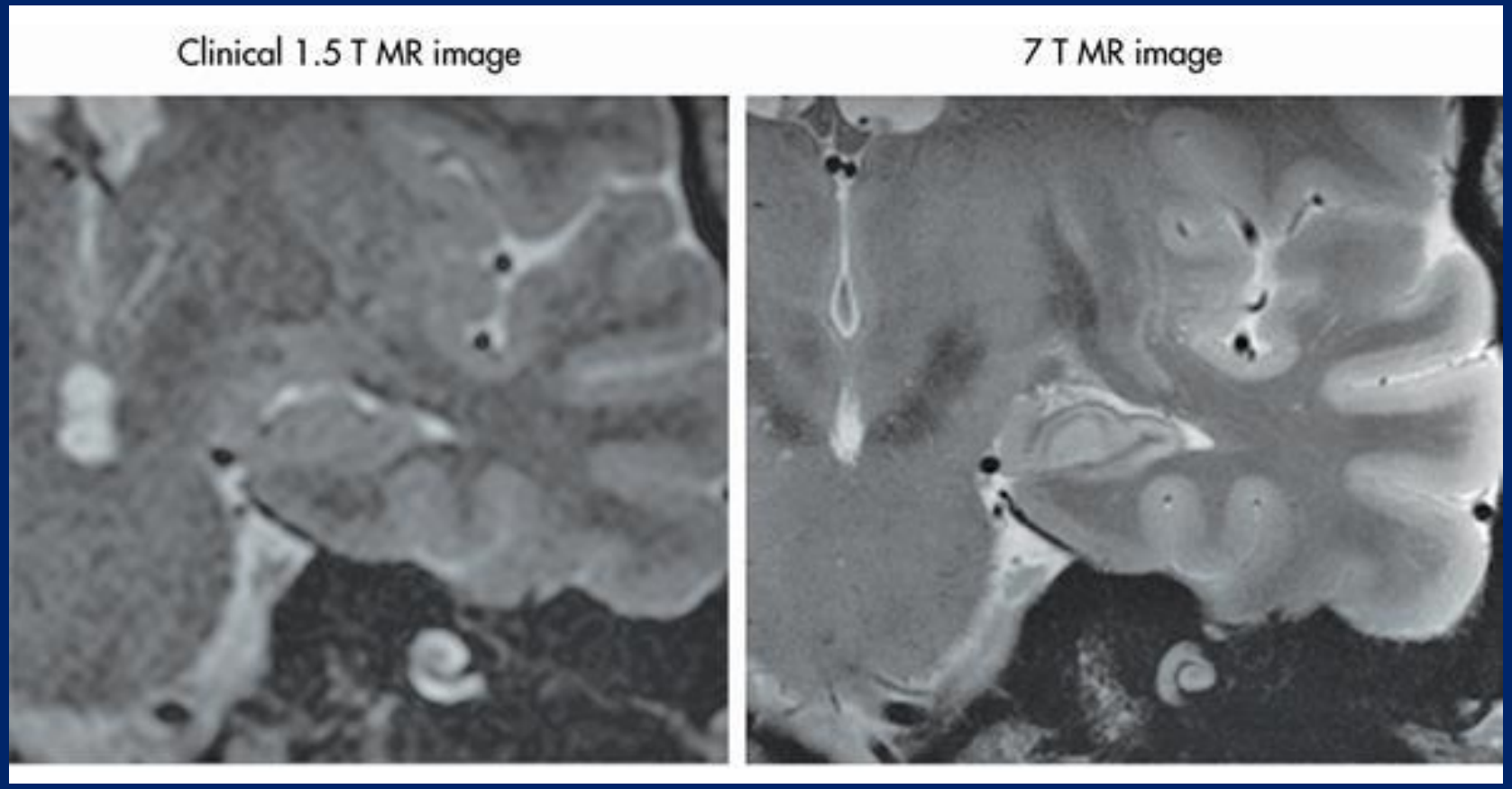
Influences on Parameter Selection

Signal-to-Noise(SNR)

- The amount of signal collected in the MR echo, compared to the background electrical noise, both from the patient and system components.

- As signal is predictable and only at TE, and noise is a constant variable in the background, an increase in signal is an increase in SNR and a decrease in signal is a decrease in SNR.
- An increase in SNR is always a good thing and what we strive for through the selection of appropriate parameters.

Signal-to-Noise(SNR)



Low SNR, very grainy appearance on the image.

High SNR, no grainy appearance

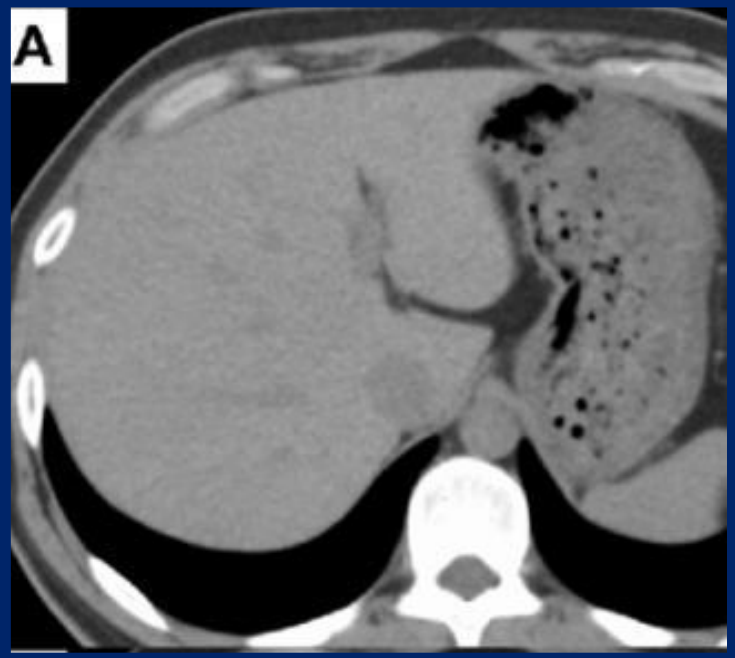
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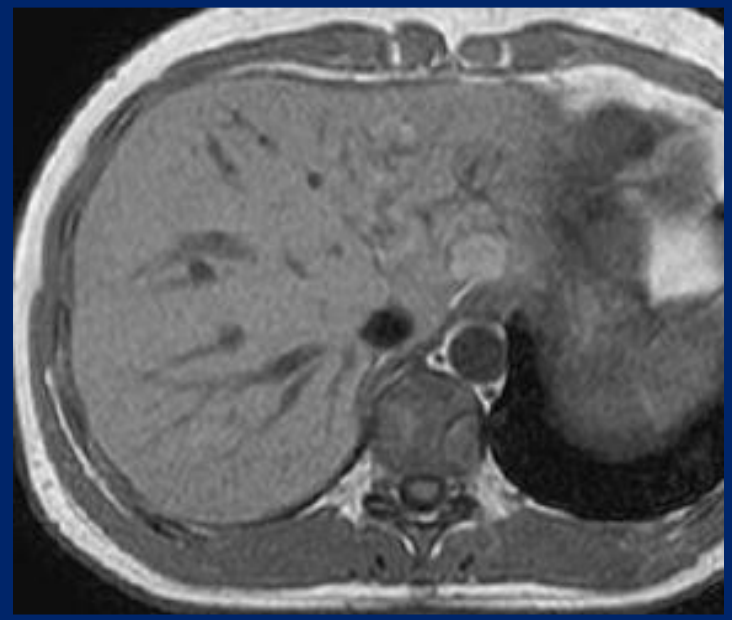
Influences on Parameter Selection

Contrast Resolution (CNR)

The ratio between the SNR from two adjacent structures.

- Most critical factor affecting image quality, as it determines the eye's ability to distinguish areas of high and low signal.
- Should be maximized to best differentiate tissues.





Influences on Parameter Selection

Spatial resolution

- The ability to distinguish two separate points in space as two separate points.
  - Controlled by voxel size
  - An effort should be made to optimize the resolution so that structures in the image can be seen clearly.

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Influences on Parameter Selection

Temporal resolution -The aspect of image quality in relation to scan time.

- There is often a relation between temporal resolution and spatial resolution, and it's usually inversely related. Meaning, high spatial resolution studies usually are longer scans, while very fast scans have poor spatial resolution.

- You should try to maintain short scan times for several reasons:
  - Minimizing motion artifacts
  - Patient comfort
  - Increasing patient throughput

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Calculation of Scan time

For a 2D study, the scan time is calculated by the following equation:

$$\frac{(TR) \times (\#\ \text{of signal averages}) \times (\#\ \text{of phase lines in Matrix})}{\#\text{Echo train}}$$

TR – repetition time.
The time it takes to fill rows in our image matrix.

NSA – number of signal averages
The number of times a signal is placed in each row in our matrix.

Phase Matrix
The number of rows in our image matrix

Echo Train
How many signals we receive for a single slice in each TR

Calculation of Scan time

Calculate the scan time of a FSE pulse sequence with an echo train of 12, a TR of 2000ms, a 256 x 256 image matrix and 2 excitations.

$$\frac{2000\text{ms} \times 2\text{NEX} \times 256}{12}$$

- 85,333ms
- To get time in seconds, divide this number by 1000
  - 85sec

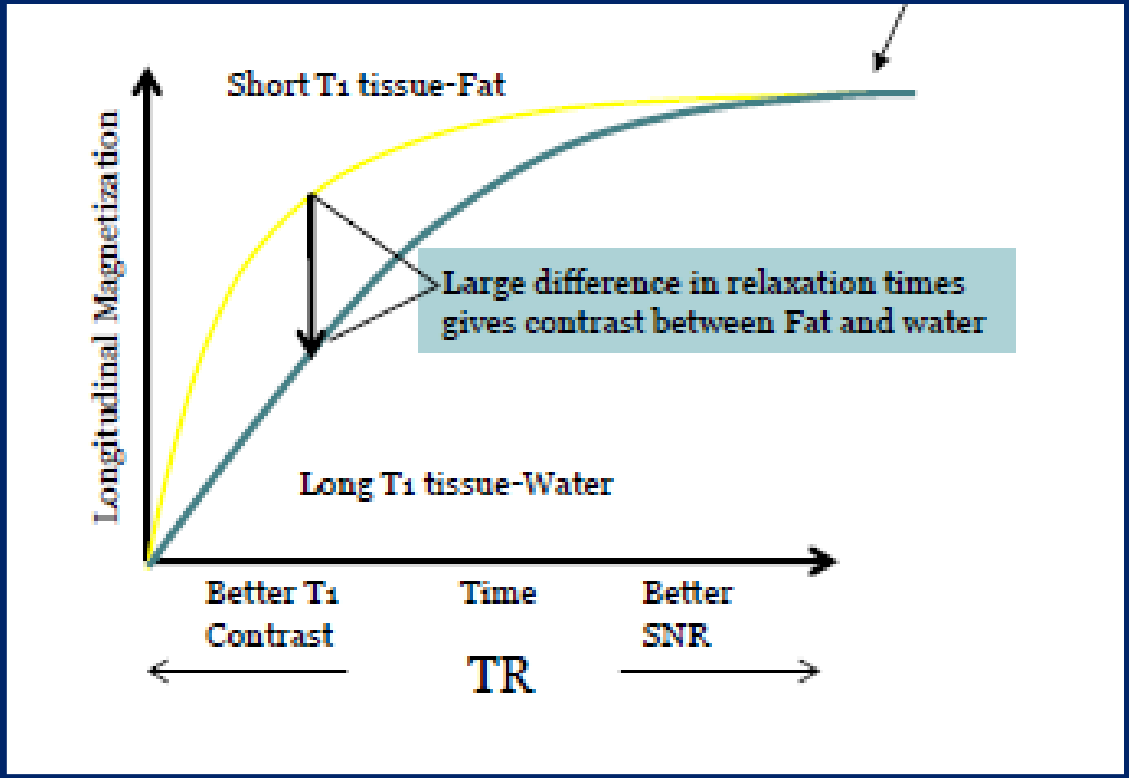
- To get time in minutes, divide the number by 60,000
  - 1.4min – this is not 1min 40sec (1 min and 25sec)
  - Multiple the decimal by 60 to get the seconds.

TR Repetition Time

Determines how much longitudinal relaxation is allowed to occur and how much NMV is available to be moved into the transverse plane to generate the MR signal.

All tissues experience T1 relaxation at different rates.

Short TR times give us high T1 contrast but, at the expense of SNR.



Trade-off

Long TR's provide greater SNR, but decreased T1 contrast.

Short TR's maximize the T1 contrast but reduce SNR.

For a spin echo pulse sequence, TRs on the order of 300-800ms are generally used to generate acceptable T1 contrast.

A TR in this range will still ensure enough longitudinal magnetization needed to generate MR echoes with enough SNR to make the image diagnostic.

Changing the TR also affects the scan time and the maximum # of slices that can be imaged during a scan.

A longer TR results in a longer scan time and a shorter TR results in a shorter scan time.

The scan time is directly proportional to the chosen TR.

Key points

Increasing the TR will:

- Increase longitudinal relaxation, thus allowing more magnetization to be moved into the transverse plane and increasing our SNR
- Decrease T1 contrast – the more relaxation that is allowed to occur, the less tissue contrast we see
- Increase scan time – Scan time and TR are directly related!
- Increase allowable # of slices

TE Echo Time

The TE is the parameter that controls the contrast between tissues in an image due to T2 decay

Varying the TE will affect both the SNR and the T2 contrast of the image.

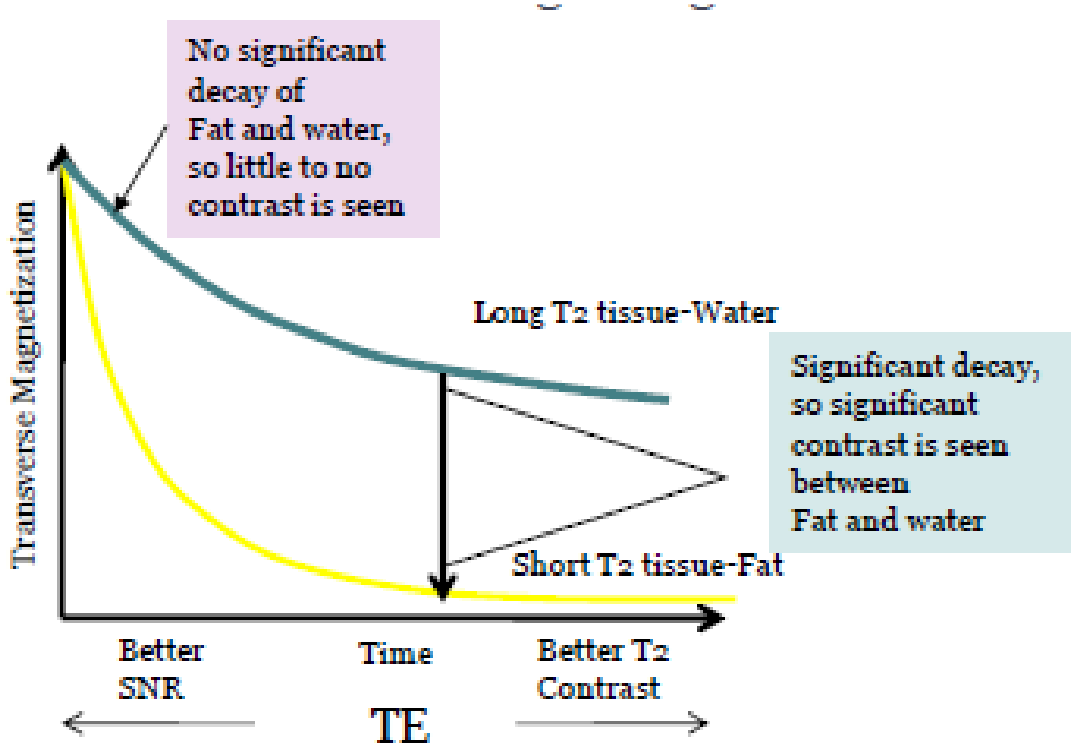
T2 contrast is the differences between the T2 times of fat and water.

The TE determines the amount of decay that is allowed to occur before the signal is received.

A long TE allows for significant decay, while a short TE allows much less decay to occur.

Utilizing a long TE will give us the biggest difference in decay times of the tissues.

T2 contrast is maximized when using a long TE.



Trade-off

- Short TE’s provide greater SNR, at the expense of T2 contrast.
- Long TE’s maximize T2 contrast, at the expense of SNR.
- For a spin echo pulse sequence, TE’s on the order of 80-120ms are generally used to generate T2-weighted images.
- TE’s in this range are long enough to maintain good T2 contrast and short enough to achieve an acceptable SNR.

Key points

Increasing the TE will:

- Increase transverse decay – again, it has no where to go but down. The more transverse decay that is allowed to occur, the lower our SNR

- Increase T2-weighted contrast

- Decrease the allowable # of slices – this should be obvious. If we are increasing our TE, say from 15ms to 90 ms, then we are going to have less dead time in our TR, so fewer slices will be allowed.

TR and TE

If we want T1-weighted images, we need to increase T1 contrast and decrease T2 contrast.

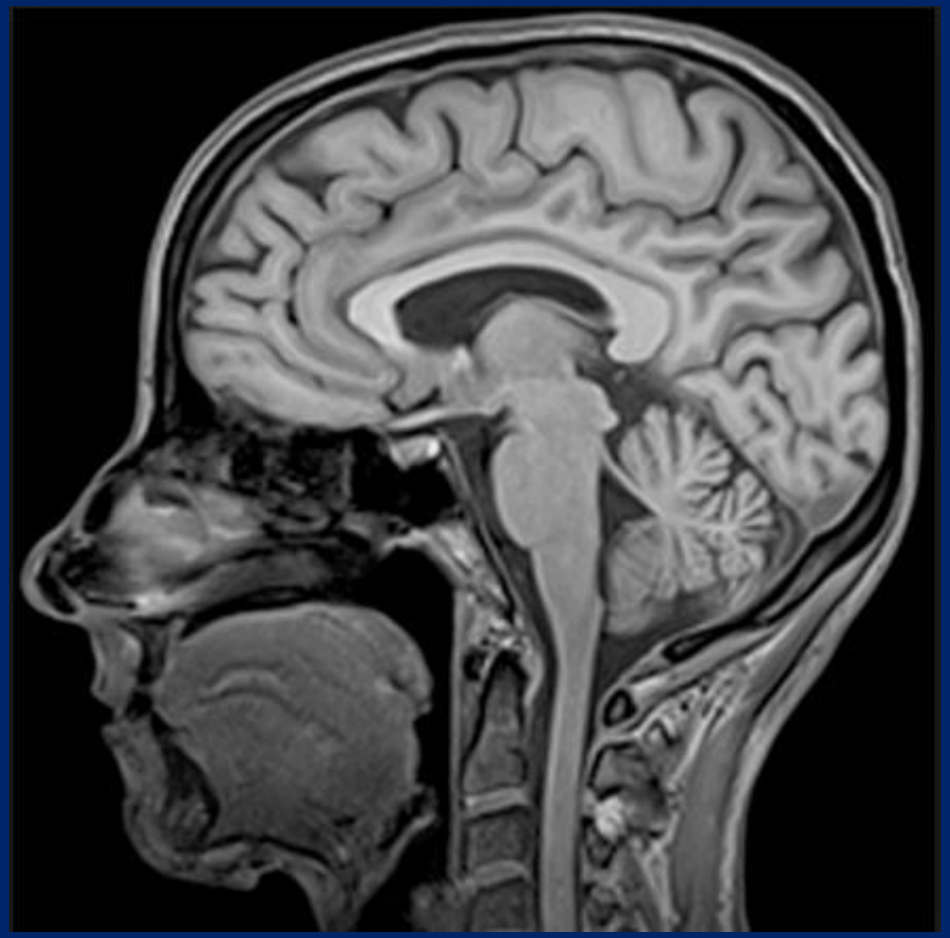
Using a short TE will decrease T2 contrast

T1-weighted images are acquired by using a short TR and a short TE.

For Spin Echo pulse sequences:

TR-Short 300-800ms

TE-Short 10-30ms



TR and TE

If we want T2-weighted images, we need to increase T2 contrast and decrease T1 contrast.

TE controls T2 contrast, TR controls T1 contrast

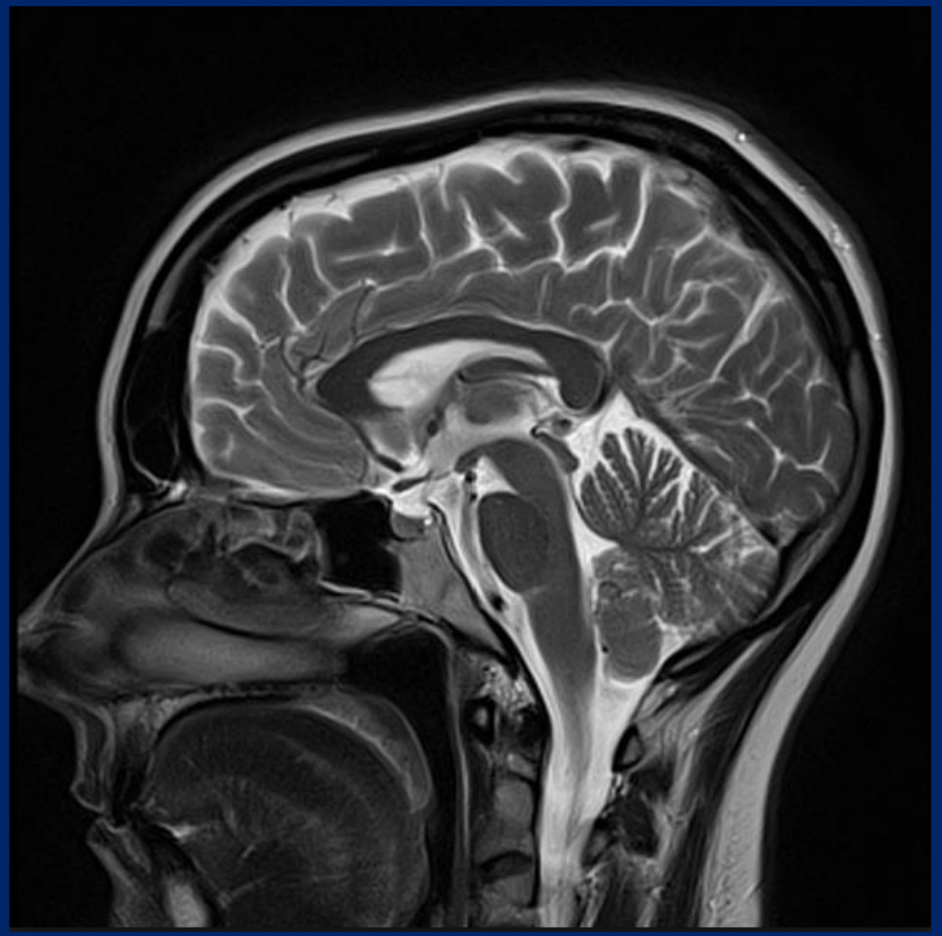
Using a long TR will decrease T1 contrast

T2-weighted images are acquired by using a long TR and a long TE.

For Spin Echo pulse sequences:

TR-Long 2000+ms (often much more)

TE-Long 80+ms (80-120ms)



Proton Density

- **Short TE and long TR yields us a proton density image.**
  - Proton density refers to the contrast in the image being based on the numbers of hydrogen protons within each tissue, per unit volume.
    - More protons in a unit of tissue, greater transverse component of magnetization, brighter the signal intensity.
    - Less protons in a unit of tissue, less transverse magnetization, darker the signal intensity.

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Proton Density

- Proton density contrast is always present, to some extent, in our images.

- When we want to see true proton density contrast, we need to suppress the effects of T1 and T2 contrast.
  - TE controls T2 contrast, TR controls T1 contrast
  - Using a long TR will decrease T1 contrast
  - Using a short TE will decrease T2 contrast

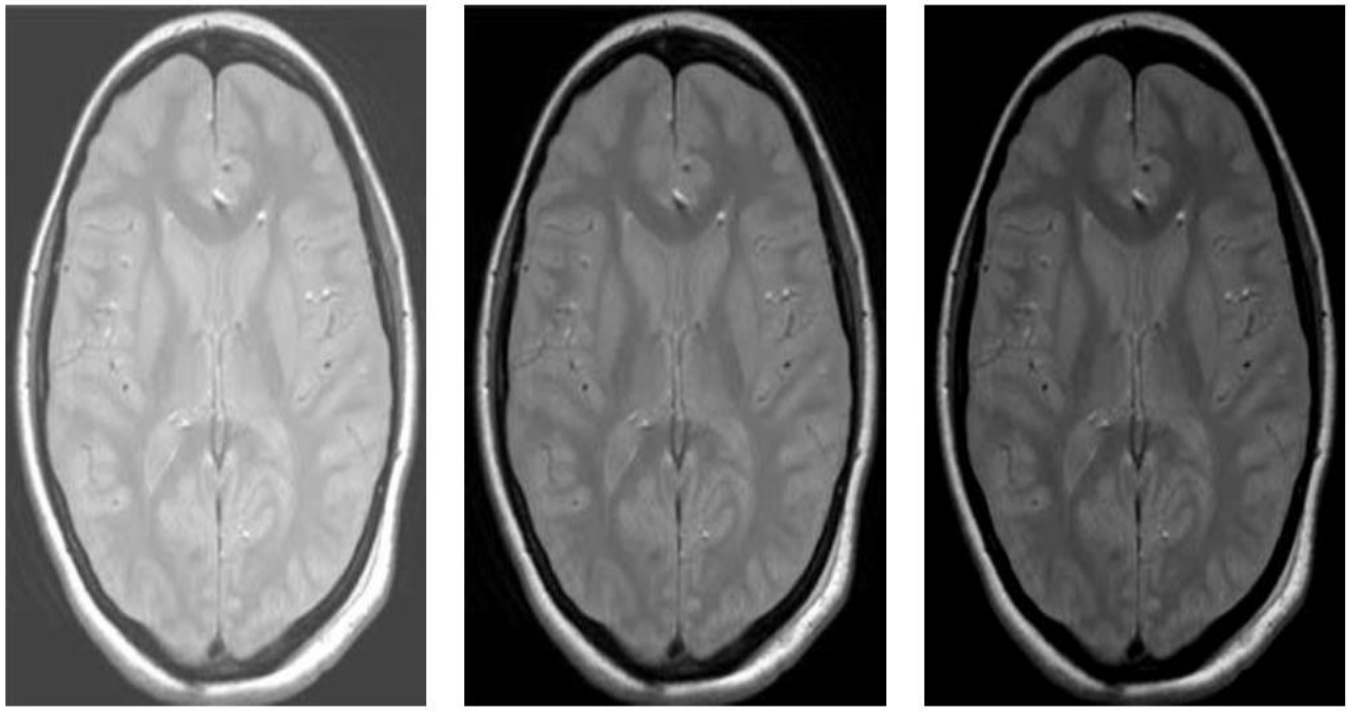
For Spin Echo pulse sequences:

- TR-Long 2000+ms
- TE-Short 20-45ms

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Proton Density

- TRs of no less than 2000ms should be used.
- TE’s of no more than 45ms should be used.



TR 2500 TR 3000 TR 3000

Poor Image Contrast

- Combining a long TE and a short TR would give us echoes with very little signal, and each echo would contain competing contrast from both T1 and T2.
- The images would have very low diagnostic quality.

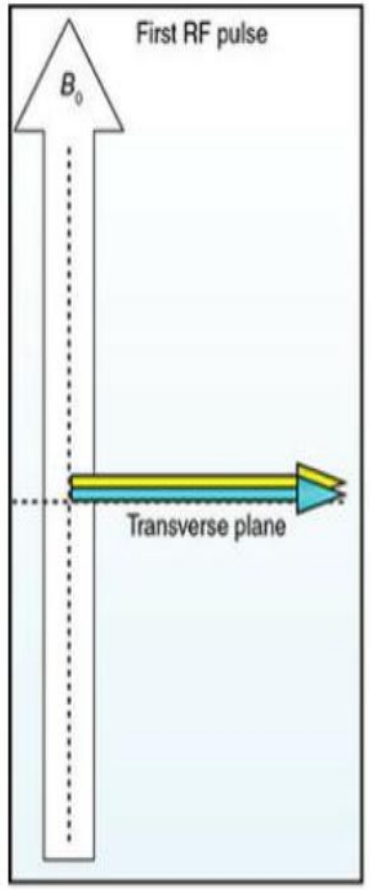


Inversion Time (TI)

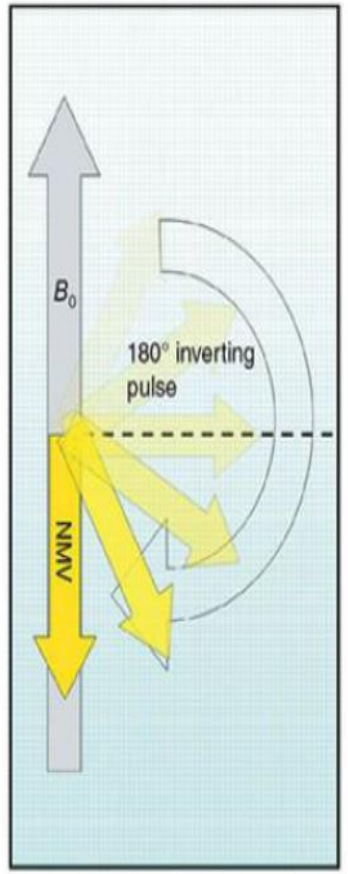
TI (time from inversion)

The time from the initial 180 RF inverting pulse to the 90 RF excitation pulse.

IR techniques are used predominantly for nulling or suppressing a tissue, i.e. getting little to no signal from tissues we may not want to see on certain sequences.



90° RF excitation pulse



180° RF inverting pulse

RF Flip Angle

The flip angle is how far the NMV moves out of alignment with B0.

Varying the RF flip angle has an effect on **SNR and on T1-weighting**.

Small flip angle reduces T1 weighting

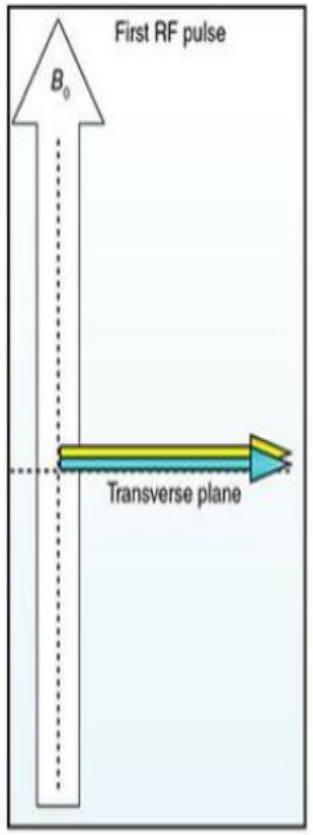
Greater longitudinal recovery equals less T1 contrast

Flip angles closer to, but less than 90 , will allow for T1 contrast with a longer TR

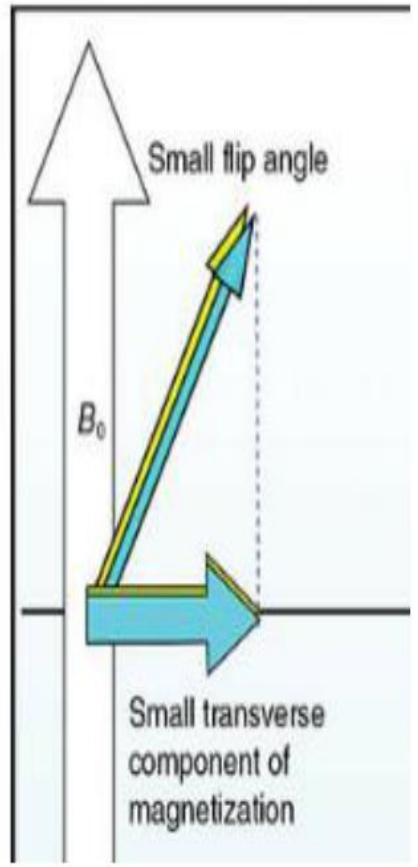
Small flip angles increase T2 weighting

Reduced T1 weighting naturally increases T2 weighting

Ernst Angle – Optimum flip angle for a specific tissue.



90° RF excitation pulse



30° RF excitation pulse

Slice Thickness

Slice thickness affects the amount of anatomy covered in the sequence, SNR, and the resolution of the MR image.

Increasing slice thickness will:

- Increase anatomical coverage – dependant upon TR
- Increase SNR – more protons in a thicker slice, better signal
- Increase partial voluming and decrease spatial resolution – thicker slice will yield us less ability to view small structures, as the signal from all the structures will be averaged together.

Matrix

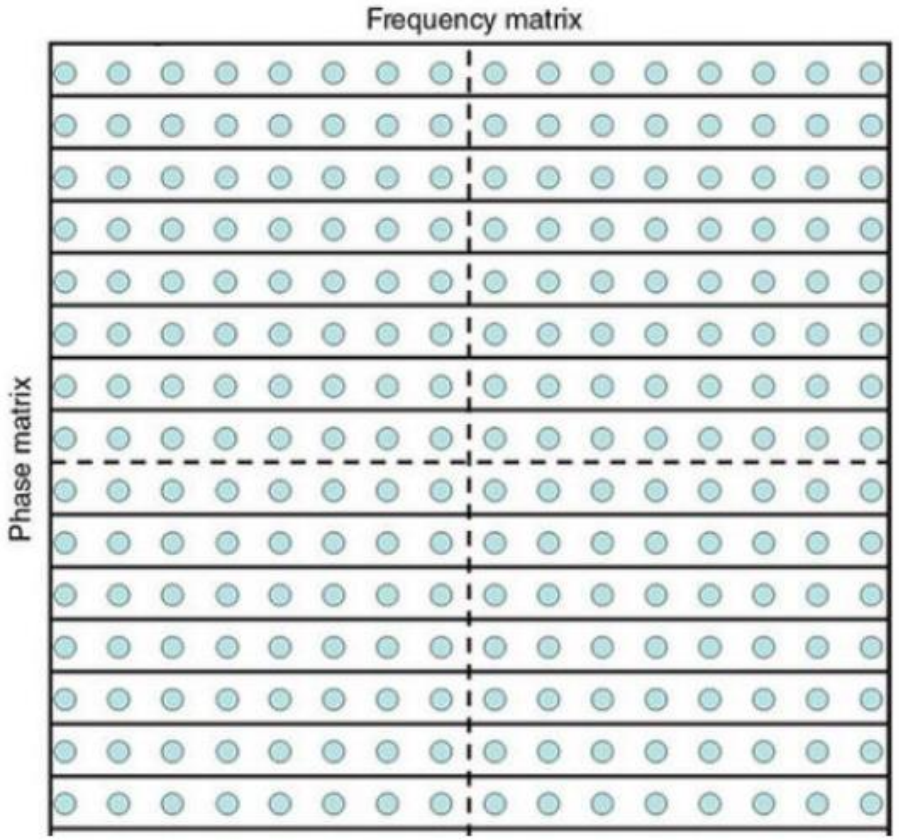
- The number of pixels in the MR image.
  - A grid of rows and columns of pixels

The matrix determines the # of pixels in the FOV.

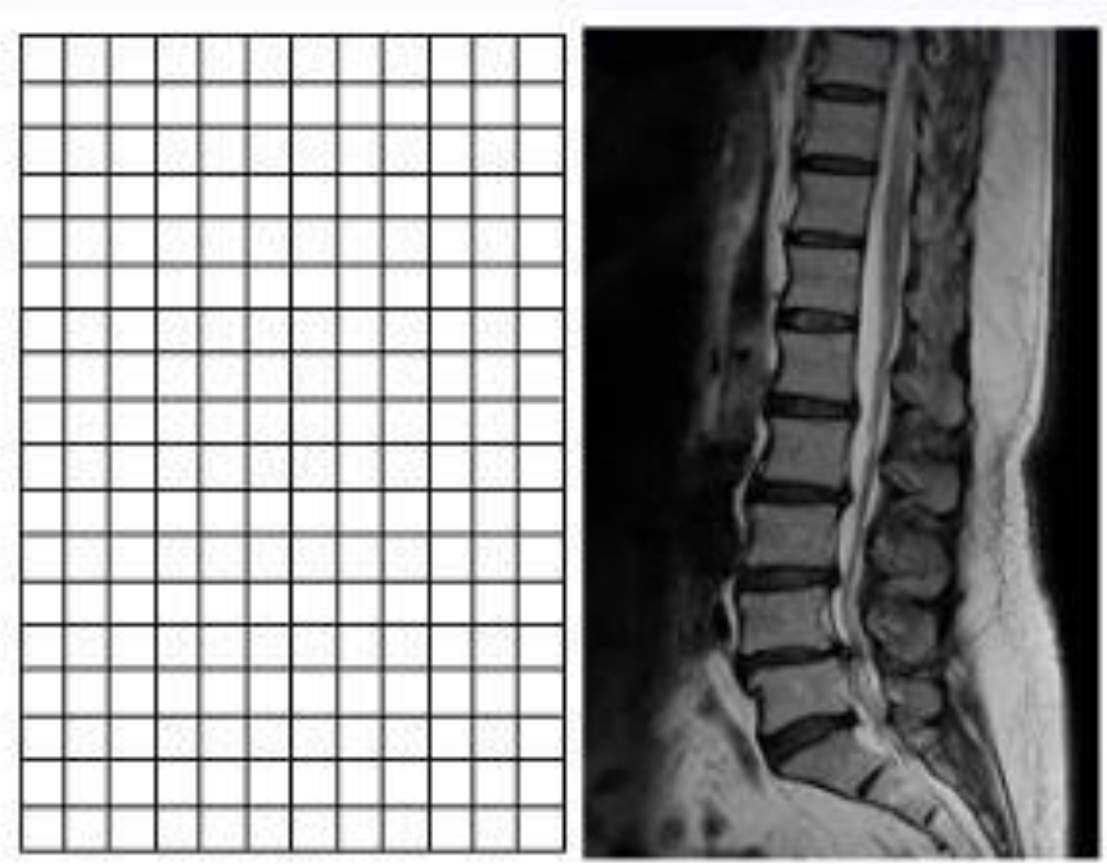
For a given FOV, the larger the matrix, the smaller the pixels.

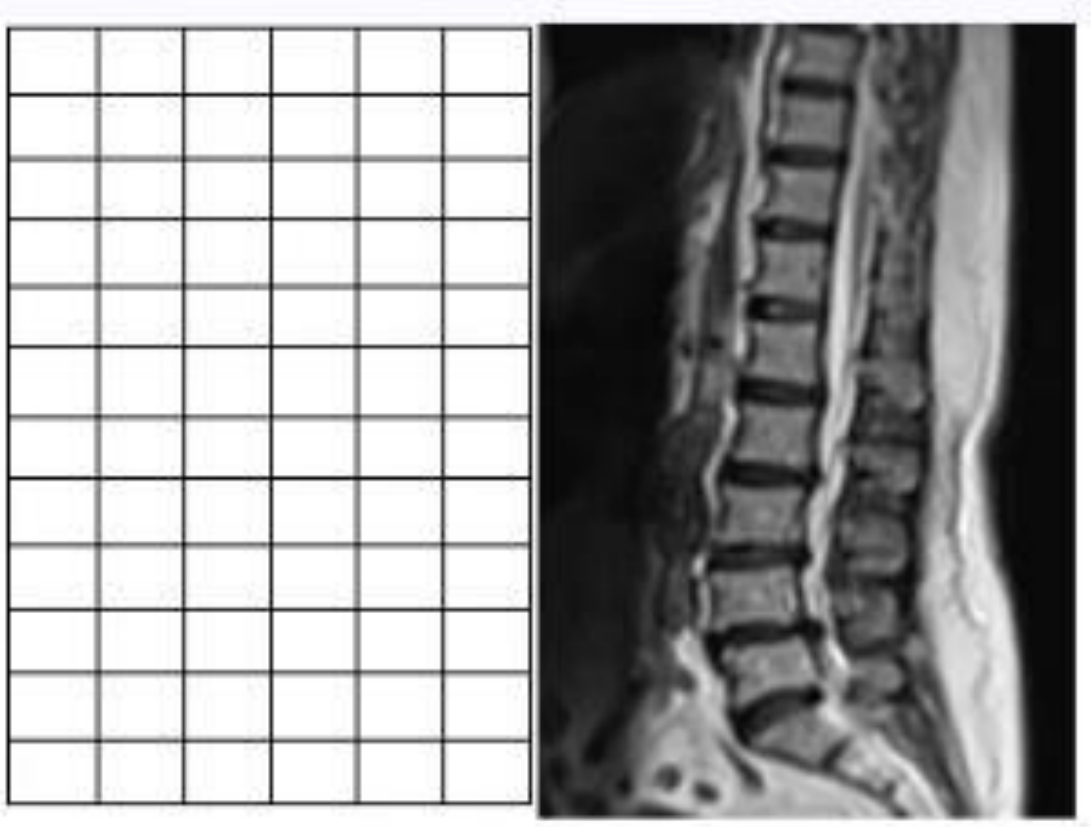
One axis is the **frequency** direction, the other is the **phase** direction.

The longer direction of the anatomy is usually the frequency direction, and the short axis of the anatomy is typically the phase direction



Matrix



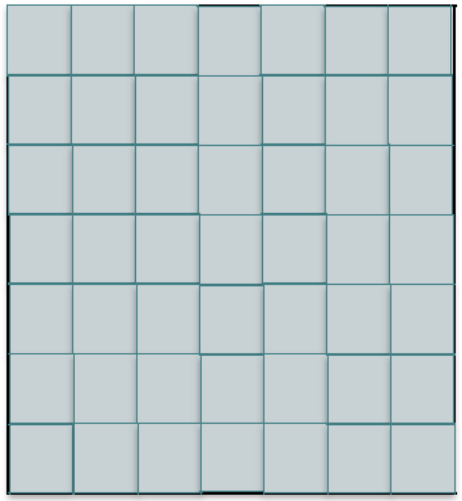


Matrix

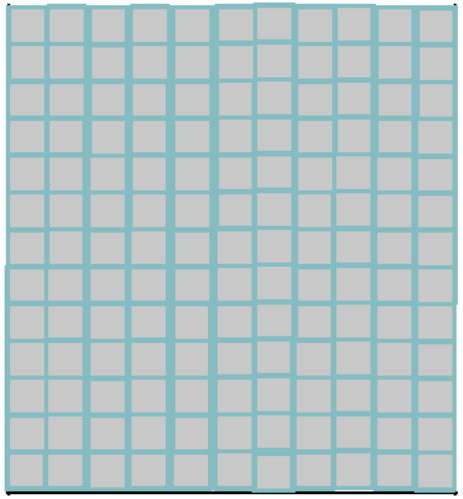
A larger matrix yields better spatial resolution, at the expense of SNR.

By increasing the image matrix, the signal must be distributed across more pixels.

This decreases the overall signal per pixel, which decreases SNR.



FOV 10mm x 10mm
7x7 Matrix



FOV 10mm x 10mm
11x11 Matrix

Matrix

Key Points:

For a given FOV, **increasing the phase encoding steps will:**

- Decrease SNR – less signal per pixel
- Increase spatial resolution – smaller structures seen as individual structures
- Increase Scan time - # of phase steps increase, so does scan time!

Increasing the frequency steps will:

- Decrease SNR – again, less signal per pixel
- Increase spatial resolution - smaller structures seen as individual structures
- Not affect scan time

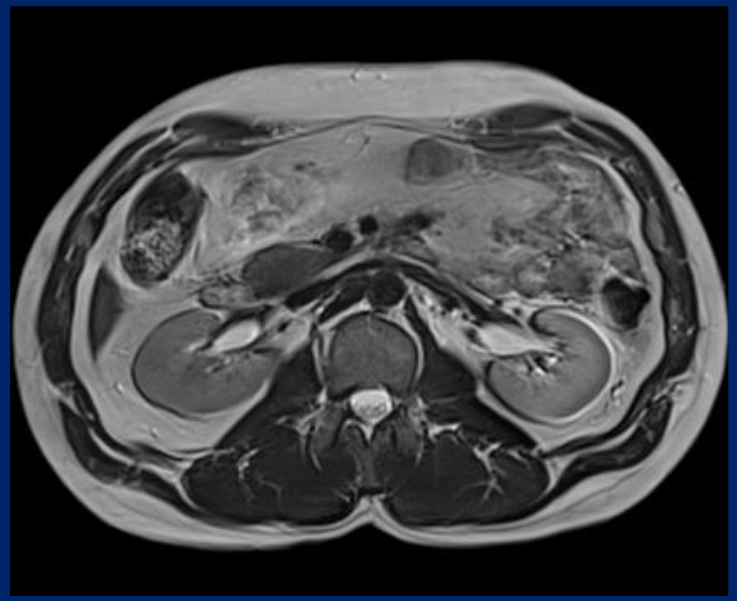
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Field of View (FOV)

(FOV) determines:

- the pixel dimensions, i.e. the pixel size.
- the amount of anatomy seen in our images.





Field of View

The FOV also affects the SNR and in-plane resolution of the image.

Similar to how a thick slice increases our SNR because more protons are in a thicker slice, a larger FOV would have more protons contributing to the signal, per pixel, than a narrow one.

Increasing the SNR by using a large FOV will decrease the spatial resolution of the resulting image.

For a given matrix, larger FOV’s results in larger pixels.

Larger pixels decreases the spatial resolution

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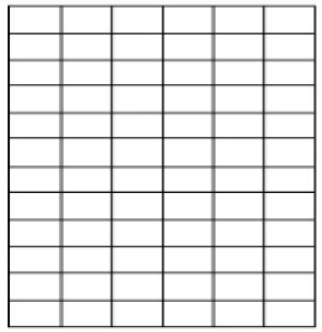
FOV

Decreasing the FOV:

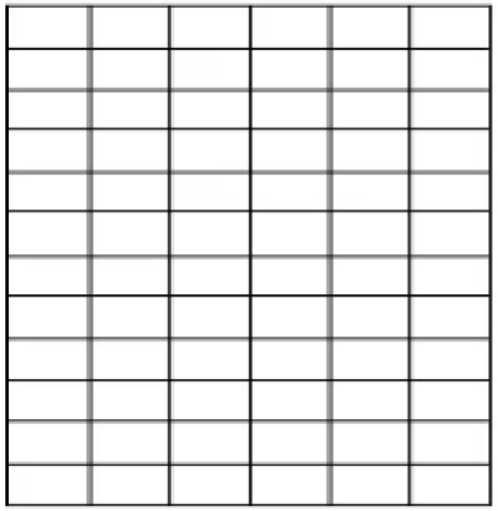
- Decrease SNR – less protons in the image
- Increase spatial resolution – smaller structures are larger on the resulting image
- For a given matrix: Decreased pixel size

Increasing the FOV:

- Increase SNR – more protons, better signal
- Decrease spatial resolution - smaller structures will be too small to see well
- For a given matrix: Increased pixel size



FOV 9mm x 9mm
12 x 6 Matrix



FOV 15mm x 15mm
12 x 6 Matrix

of signal averages

Also known as the # of excitations or the # of acquisitions (NEX, NSA, NAQ).

It is the # of times echoes are collected at the same amplitude of the phase encoding gradient.

The NEX controls the amount of data stored in each line of K space.

Increasing the signal averages:

- Increases SNR – we are increasing the number of excitations. This equals more signal.
- Increases scan time – if we have a NEX of 2 and 256 phase steps in our matrix, then 512 TR's are required. (256 x 2 samplings)
- Decreases motion artifacts – like noise, motion is random and will diminish with multiple samplings.

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Parameters/Trade offs

Parameter	Trade offs
Increasing TR	Increase longitudinal relaxation, increased SNR Decrease T1 contrast Increase allowable # of slices Increase scan time
Increase TE	Increase transverse decay, decreased SNR Increase T2 contrast Decrease the allowable # of slices
TI	Short TI – Nulls fat Long TI – Decrease T1 contrast, nulls CSF
Flip Angle	Reduced flip angles decrease T1 contrast and increase T2 contrast
Increased Slice Thickness/Transmit Bandwidth	Increase anatomical coverage Increase SNR Increase partial voluming Decrease spatial resolution
Increasing Gap	Decrease crosstalk Increase anatomical coverage Risk missing micro-pathology

Parameters/Trade offs

Parameter	Trade offs
Increased Phase Matrix	Decrease SNR Increase spatial resolution Increase Scan time
Increased Frequency Matrix	Decrease SNR Increase spatial resolution Doesn't affect scan time
Decrease FOV	Decrease SNR Increase spatial resolution For a given matrix: Decrease pixel size
Increase Echo Train	Decrease scan time Decrease SNR
Increase NEX	Increases SNR Increases scan time Decreases motion artifacts
Increase Receive Bandwidth	Decrease SNR Decrease chemical shift and hardware artifacts Doesn't affect scan time Decreases minimum allowable TE

References

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6. Ernst Angle Retrieved from: http://mri-q.com/optimal-flip-angle.html in 2016. All images used with permission from page owner. Email granting permission is available upon request.