Al-Mustaqbal University
College of Health and Medical Technologies
Radiological Techniques Department

Magnetic Resonance Imaging

First Semester

Lecture 3,4 : Concepts of MRI

2024/2025

Introduction:

MRI technicians' students need to understand MRI concepts for several reasons, including:

- **Performing MRI exams:** MRI technicians need to have a thorough understanding of the physical principles of MRI and the general concepts of image contrast.
- **MRI technicians need to understand MRI concepts to perform MRI exams effectively, ensure MRI safety, interpret MRI results accurately, and keep up-to date with MRI technology.**
- MRI concepts can be **learned to the student through MRI technology theoretical and practical lectures**, continuing education courses. It is important for MRI technician students to stay up-to-date with the latest MRI technology and concepts to provide the best possible care for their patients in the future.

MRI components

Scanners of MRI come in many varieties. The most important hardware within MRI system are as follows (fig 1):

1.**A large magnet to** generate the magnetic field. The static magnetic field in MRI system can be created by:

A- Permanent magnets, or B- Electromagnets.

2. **Shim coils to** make the magnetic field as homogeneous as possible.

3. **A radiofrequency (RF) coil** to transmit a radio signal into the body part being imaged.

4. **A receiver coil to** detect the returning radio signals.

5. **Gradient coils to** provide spatial localization of the signals.

6. **A computer to** reconstruct the radio signals into the final image.

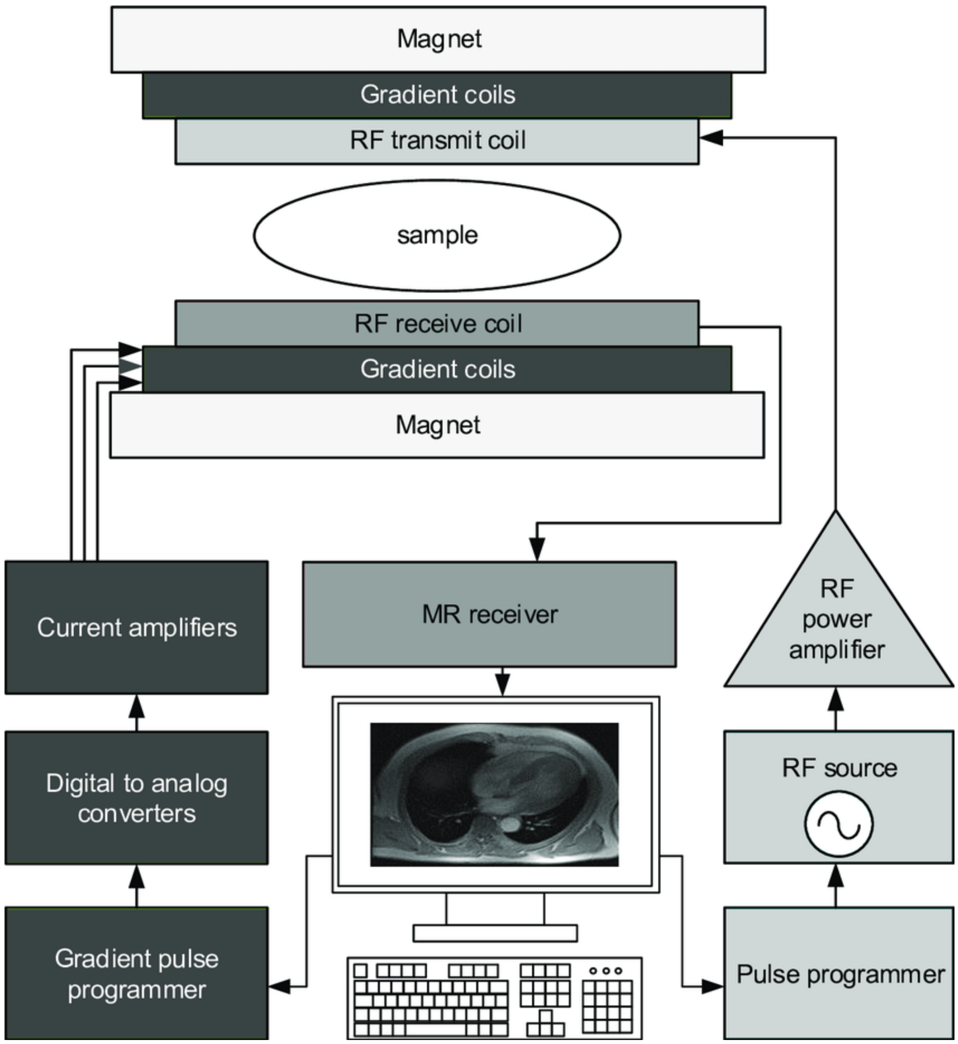


Fig.1: Block diagram of a typical magnetic resonance imaging scanner.

Concepts of MRI image: -

An image has **contrast** if there are areas of **high signal** **(white on the image),** as well as areas of **low signal** **(dark on the image).** Some areas have an **intermediate signal** **(shades of grey in-between white and black).**

Terminology

Intensity: When describing most MRI sequences, **we refer to the shade of grey of tissues or fluid with the word intensity, leading to the following absolute terms:**

A - **high signal intensity** = white
B - **intermediate signal intensity** = grey
C - **low signal intensity** = black

- Often, we refer to the appearance by relative terms:

A-**hyperintense** = brighter than the thing we are comparing to it.
B-**isointense** = same brightness as the thing we are comparing to it.
C-**hypointense** = darker than the thing we are comparing to it.

Parameters that affect image contrast: The image contrast is controlled by two groups of parameters:

A. Extrinsic contrast parameters: which are controlled by the system operator; These include the following: -

1- **Repetition time (TR).** This is **the time from the application of one RF pulse to the application of the next.** It is measured in milliseconds (ms). The TR affects the length of a relaxation period after the application of one RF excitation pulse to the beginning of the next.

2- **Echo time (TE).** This **is the time between an RF excitation pulse and the collection of the signal.** The TE affects the length of the relaxation period after the removal of an RF excitation pulse and the peak of the signals received in the receiver coil. It is also measured in ms. (fig 2)

3- **Flip angle.** This is the angle through which the NMV is moved as a result of a RF excitation pulse.

4- **Turbo-factor or echo train length (ETL/TF).**

5- **Time from inversion (TI). The time between inversion 180 degree and excitatory 90-degree pulses is called as 'time to invert or TI'** . It is used in certain pulse sequences to manipulate the contrast between different tissues in the image.

6- **'b' value:** is a factor that reflects the **strength and timing** of the gradients used **to generate diffusion-weighted images**.

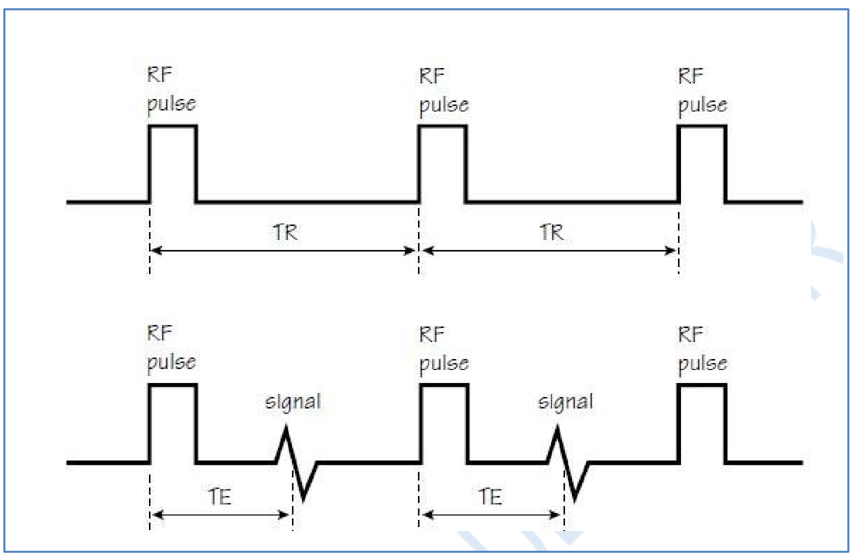


Fig 2: A basic pulse sequence

B. Intrinsic contrast mechanism: Which do not come under the operator's control; These include:

1. T1 recovery.
2. T2 decay.
3. Proton density.
4. Flow.
5. Apparent diffusion coefficient (ADC): is a measure of the magnitude of diffusion (of water molecules) within tissue.

Technical factors influencing the image contrast and quality:

In MRI, a **protocol** is **defined as a set of rules which include a variety of different parameters that we select at the imaging consol**. Protocols are judged by how well they show anatomy and pathology, and this is based on producing images that demonstrate the following four characteristics: -

1. **High signal-to-noise ratio (SNR).**
2. **Good contrast-to-noise ratio (CNR).**
3. **High spatial resolution.**
4. **Short scan time.**

In an ideal world, all four of these characteristics are achieved in every image. However, due to a variety of constraints, this is not usually possible. Optimizing parameters in favor of one of the aforementioned characteristics usually means another. The skill lies in making informed decisions about which is most important for each patient and pathology, and using knowledge of underpinning physics to appropriately balance protocol parameters.

*Signal-to-noise ratio (SNR):

The SNR is defined as the ratio of the amplitude of signal received to the average amplitude of the background noise.

Signal is cumulative and predictable. **It occurs at, or near, time TE and at specific frequencies at, the Larmor frequency.** It depends on many factors and can be altered. Noise, on the other hand, **is not predictable and it occurs at all frequencies and is also random in time and space**. In the context of MRI, the **main source of noise is from thermal motion in the patient but it is also generated by background electrical noise of the system. Noise is constant for every patient and depends on the build of the patient, the area under examination, and the inherent noise of the system**. **The purpose of optimizing SNR is to make the contribution from signal larger than that from noise**. As signal is predictable and noise is not, this usually means using measures that increase signal relative to noise, rather than reducing noise relative to signal.

Therefore, any factor that affects signal amplitude affects the SNR. These are as follows:

1-Magnetic field strength of the system

2- Proton density of the area under examination

3- Coil type and position

4-TR, TE, and flip angle

5-Number of signal averages (NSA)

6-Receive bandwidth

7-Voxel volume

1-Magnetic field strength:

The magnetic field strength plays an important part in determining SNR. As **field strength increases, the NMV increases and there is more available magnetization to image the patient. SNR therefore increases.** Although the magnetic field strength cannot be altered, when imaging with low-field systems, SNR may be compromised, and it might be necessary to alter protocol parameters that boost the SNR.

2-Proton density of the area under examination:

The number of protons in the area under examination determines the amplitude of received signal. **Areas of low proton density (such as the lungs) have low signal and therefore low SNR, whereas areas with a high proton density (such as the pelvis) have high signal and therefore high SNR.**

3-Type of coil:

The type of coil affects the amount of received signal and therefore the SNR. **Larger coils receive more noise in proportion to signal than smaller coils because noise is received from the entire receiving volume of the coil.** **Quadrature coils** increase SNR because several coils are used to receive signal. **Phased array coils** increase SNR as the data from several coils are added together. **Surface coils placed close to the area under examination also increase SNR. The use of the appropriate receiver coil plays an extremely important role in optimizing SNR.** **The position of the coil** is also very important for maximizing SNR. To induce maximum signal, the coil must be **positioned in the transverse plane perpendicular to B0**.

Angling the coil, as sometimes happens when using surface coils, results in a reduction of SNR. (fig 3)

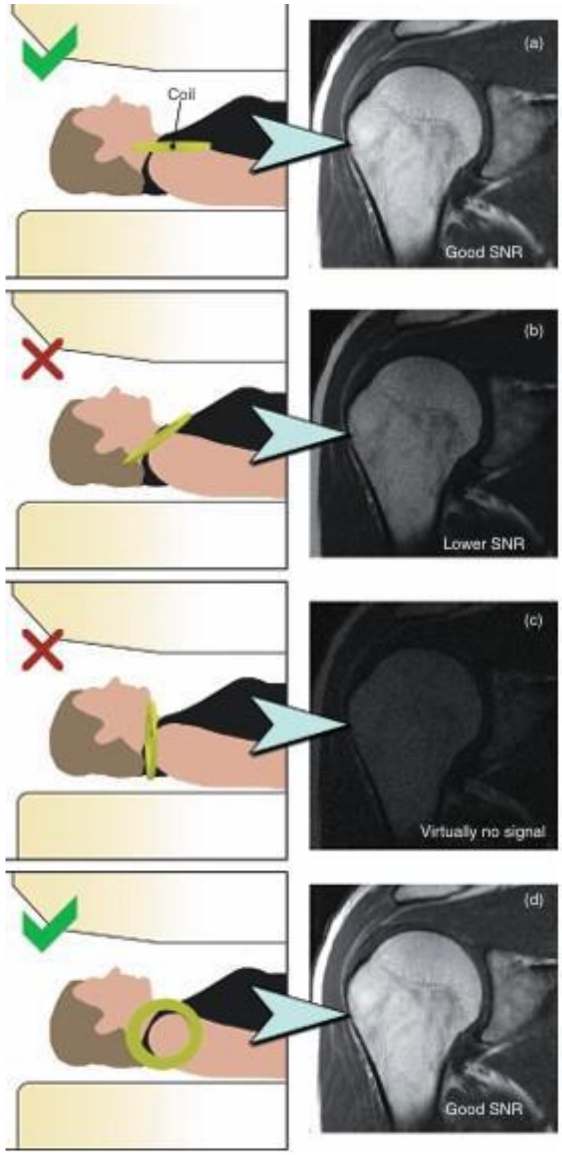


Fig.3: Coil position vs SNR

4-TR, TE, and flip angle:

-**<u>The TR controls</u> the amount of longitudinal magnetization that recovers before the next RF excitation pulse is applied**. A long TR allows full recovery of longitudinal magnetization so that more is available to be flipped into the transverse plane in the next TR. A short TR does not allow full recovery of longitudinal magnetization so less is available to be flipped. Look at Figure (4) where the TR increases from 140 to 700 ms (at 1.5 T). **The SNR improves as the TR increases.**

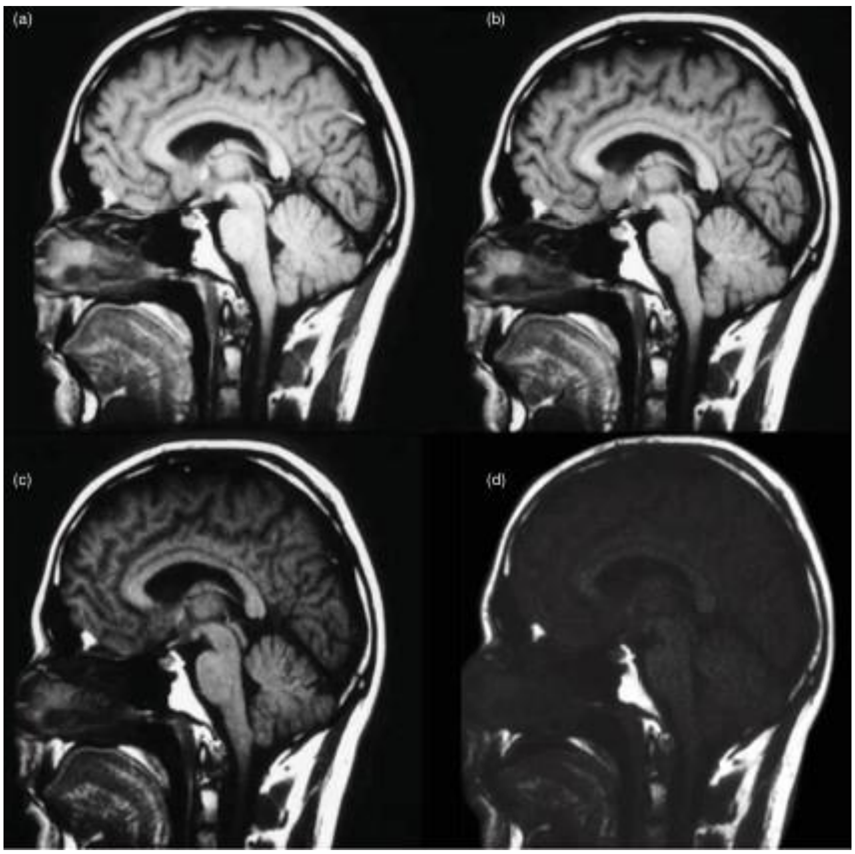


Fig.4: (a) TR 700 ms, (b) TR 500 ms, (c) TR 300 ms, (d) TR 140 ms.

-**<u>The flip angle</u> controls the amount of transverse magnetization created by the RF excitation pulse, which induces a signal in the receiver coil** (Figure 5). If the TR is long, maximum signal amplitude is created with flip angles of 90° because full recovery of longitudinal magnetization occurs with a long TR, and this is fully converted into transverse magnetization by a 90° flip angle. Look at Figures (6) in which the flip angle changes from 10° to 90°. **SNR significantly decreases in the lower flip angle image.**

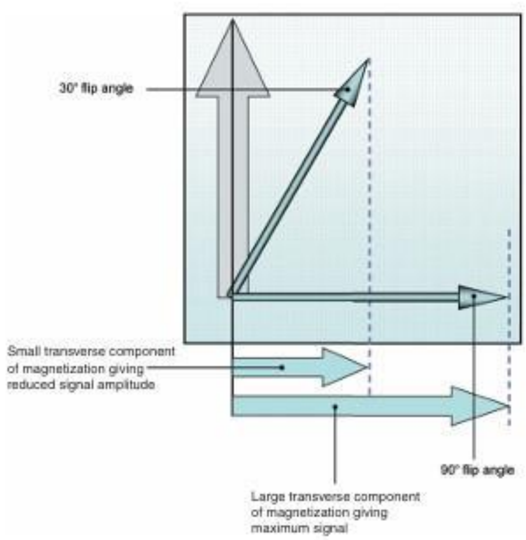
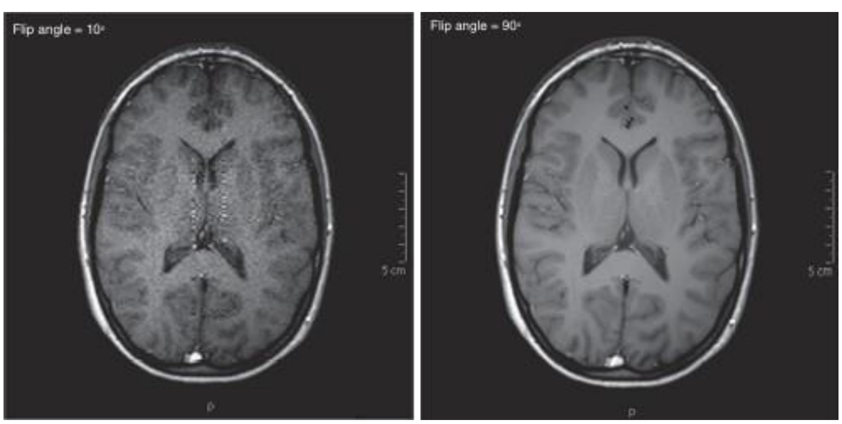


Fig.5: Flip angle vs SNR.



(A) (B)

Fig.6: Axial gradient-echo image of the brain using a flip angle of 10° at 3 T(a) & 90° at 3 T (b).

- **The TE controls** the amount of coherent transverse magnetization that decays before an echo is collected. **A long TE allows considerable decay of coherent transverse magnetization before the echo is collected, while a short TE does not. Look at Figure (7) where the TE increases from 11 to 80 ms (at 1.5T). SNR decreases as the TE increases because there is less transverse magnetization available to rephase and produce an echo.**

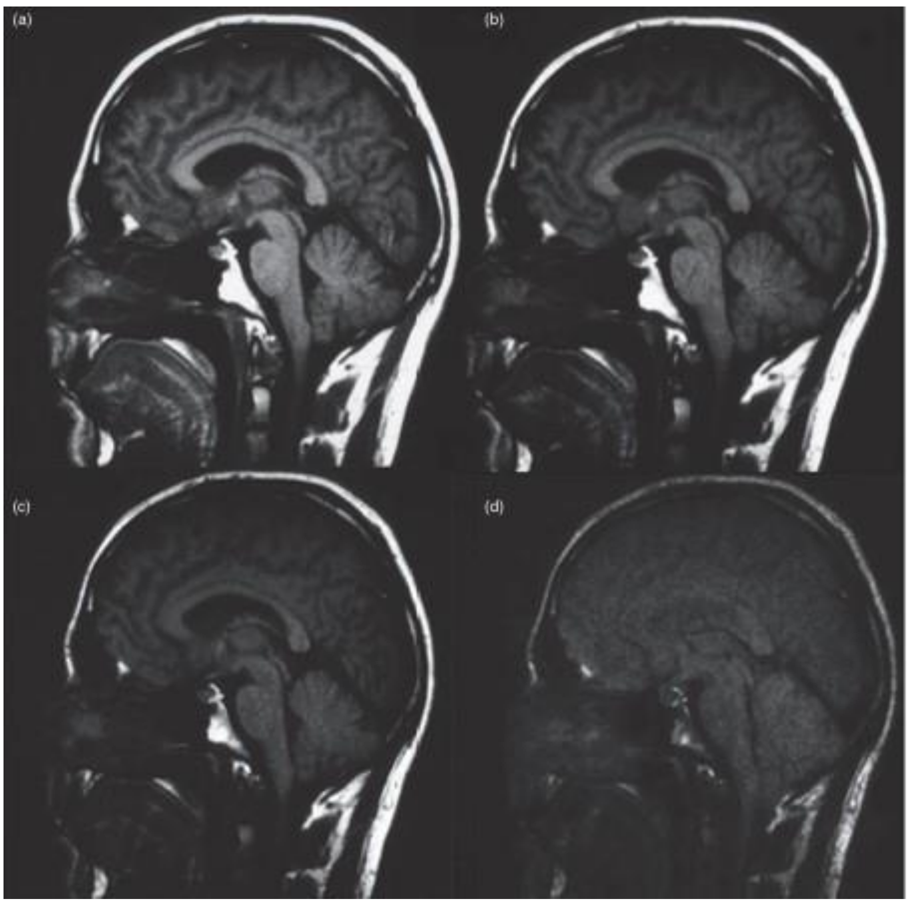


Figure 7: (a) TE 11 ms, (b) TE 20 ms, (c) TE 40 ms, (d) TE 80 ms

5- Number of excitation or number of signal average (NEX/NSA):

Every individual signal which contributes to form a MR image, can be received once or collected several times using repeated excitations. Hence, the average signal value is used to generate the image. **When the number of excitations is increased, the error (the noise) doubt and the measurements are more precise**. **In practice, the number of excitations ranges from 1 to 6.** The number of excitations (Nex) implies the number of times a particular line in sampled in K space. **K space refers to the raw data of an image.** **By increasing the number of excitations, the SNR is improved and vice versa.** (fig 8)

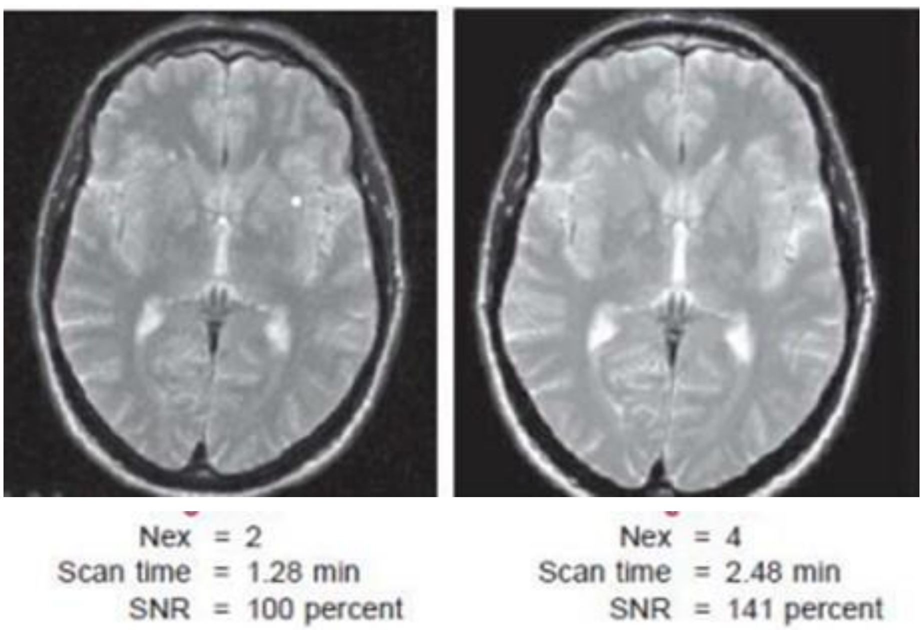


Fig 8: SNR vs NSA

6-Receive bandwidth:

(BW) A general term referring to a range of frequencies (frequencies contained in a signal or passed by a signal processing system). This is the range of frequencies that are acquired by the readout gradient. **If the bandwidth is reduced to half, SNR is increased by 40% and the sampling time increased also.**

7-voxel volume:

The building unit of a digital image is a pixel. The brightness of the pixel represents the strength of the MRI signal generated by a unit volume of patient tissue (voxel). (fig 9). **Large voxels contain more spins or nuclei than small voxels and therefore have more nuclei to contribute toward signal.** **Large voxels consequently have a higher SNR than small voxels** (Figure 10). **SNR is therefore proportional to the voxel volume, and any parameter that alters the size of the voxel changes the SNR.**

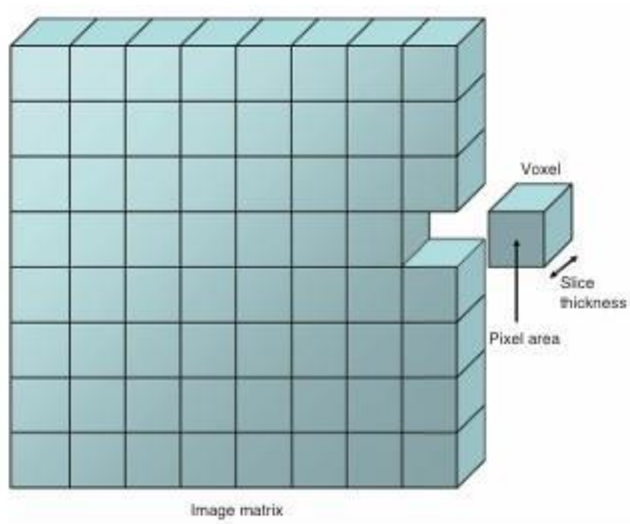


Fig 9: The voxel. The large blue square is the FOV.

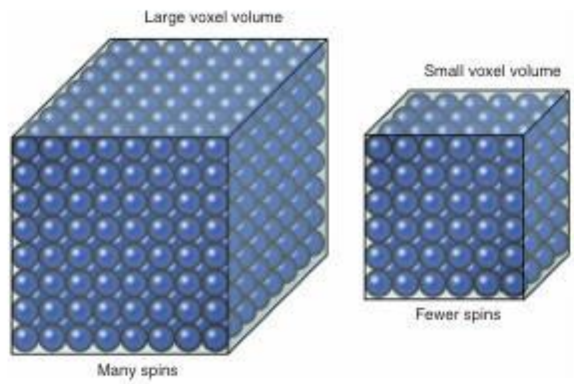


Fig 10: Voxel volume and SNR

Contrast to noise ratio (CNR):

CNR is defined as the difference in the SNR between two adjacent areas. It is controlled by the same factors that affect SNR. CNR is probably the most critical factor affecting image quality, as it directly determines the eye's **ability to distinguish areas of high signal from areas of low signal.**

Spatial resolution:

Spatial resolution is the ability to distinguish between two points as separate and distinct, and is controlled by the voxel size. Small voxels result in high spatial resolution, as small structures are easily differentiated. Large voxels, on the other hand, result in low spatial resolution, as small structures are not resolved so well.

Scan time:

The scan time is the time to complete data acquisition or the time to fill k-space. Scan time optimization is important, as long scan times give the patient more chance to move during the acquisition. Any movement of the patient is likely to degrade images.