Magnetic Resonance and Medical Imaging

Lect. 2 - 4th year /Medical Physics

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Historical Trail

- -If someone wanted to make an image of a patient 150 years ago, what could have been done Actually, not much. At that time, only photography or hand-drawn images were available.
- Both types of such images use the narrow band of the electromagnetic spectrum called the visible light region (**Figure 1-1**).

- -Electromagnetic radiation can be characterized by any one of three parameters:

  (energy, wavelength, and phase) .
- -The frequency is sometimes used to describe the wave character of electromagnetic radiation but it is basically equivalent to the wavelength since the wavelength is just the speed divided by the frequency and the speed of light is a constant, c (~3 ×10^8 m/s).

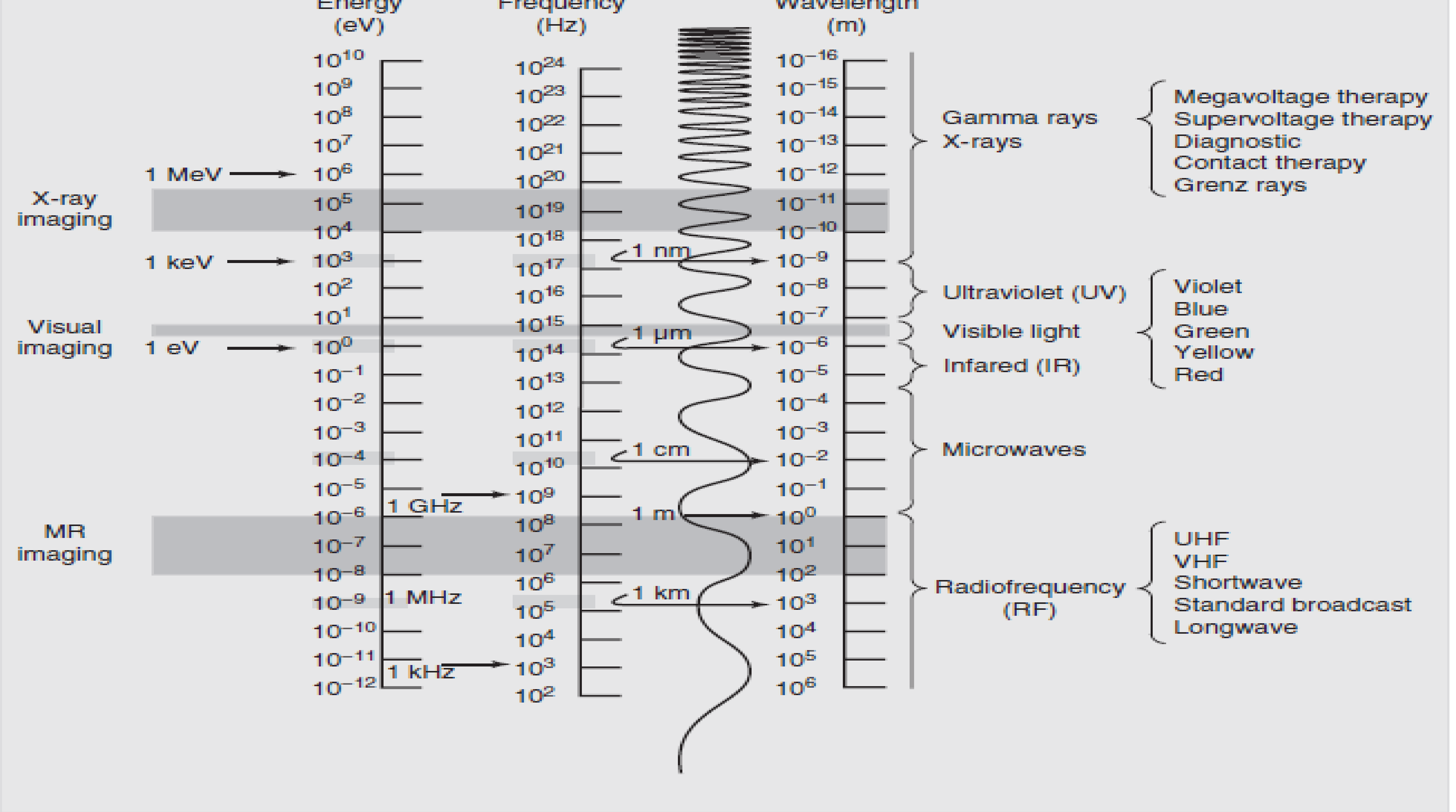

FIGURE 1-1 The electromagnetic spectrum showing values of energy, frequency, and wavelength for the imagin windows of visible light, x-rays, and radio waves.

- -After Thomas Edison’s early work, engineers and physicists worked to develop radio communications. Electrons must oscillate in a conductor to create a radio emission

- -This requires the construction of an electronic circuit called an oscillator. The oscillator is the basis for radio electronics.
- The electromagnetic radiation produced by the oscillator is called a radiofrequency (RF) emission.

- -Physicists identify this radiation according to the frequency of oscillation.
- - RF radiation extends over a range from 3 kHz to 3 GHz.
- -Commercial broadcasts such as AM radio FM radio, and television (TV) are similarly identified.
- -The AM RF band ranges from 540 to 1640 kHz, and the FM RF band ranges from 88 to 108 MHz. TV broadcast ranges from 54 to 806 MHz, which includes both VHF and UHF
- -Magnetic resonance images are made with RF in the range from approximately 10 to 300 MHz

- - Use of the RF region of the electromagnetic spectrum to produce an image is especially spectacular.
- It is based on an **analytical procedure** called nuclear magnetic resonance (NMR) and was first called nuclear magnetic resonance imaging (NMRI).

- Some of the leaders in radiology were concerned about using the word **nuclear** around patients, since NMRI really didn't involve any **kind of ionizing radiation**. As a result, that word was dropped early in the development of this imaging process, and we are left with magnetic resonance imaging (MRI).

- How is a magnetic resonance (MR) image made?

- -For a visible image, radiation is **reflected from the body**.

- -For an x-ray image, **radiation is transmitted through the body.**
-
- For an MR image, the patient is **stimulated so that electromagnetic radiation is emitted from the body** Through the use of some clever methods, the emitted signal is then detected, interpreted, and used to produce an image (Figure 1-2).

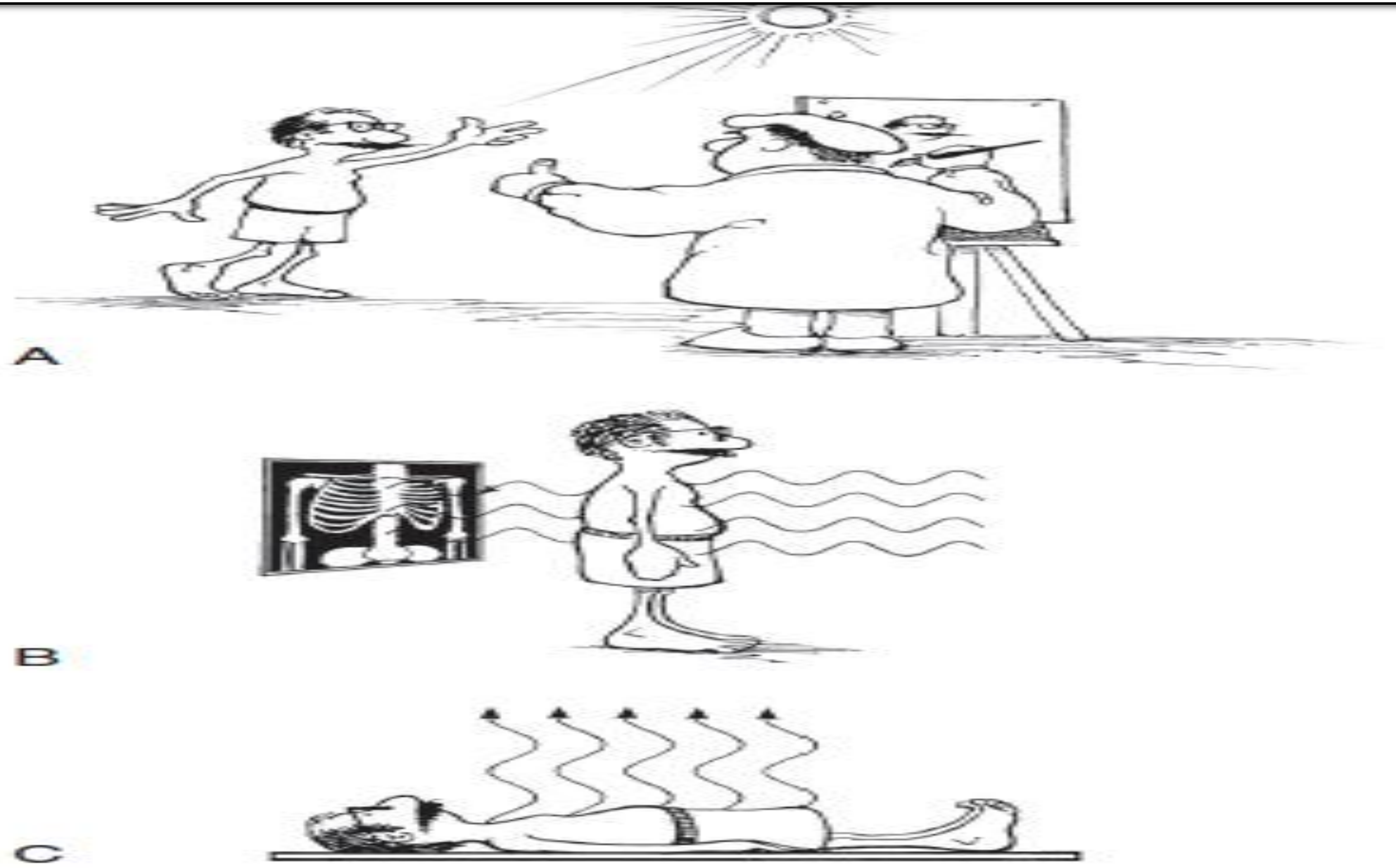

FIGURE 1-2 How images are made using the three regions of the electromagnetic spectrum. **A,** Reflected visible light. **B,** Transmitted x-rays. **C,** Emitted radiofrequency.

Felix Bloch

- -Magnetic fields associated with atoms and nuclei were first described in the 1930s. Otto Stern and Isador Rabi each received a Nobel Prize in physics for their work on atomic and nuclear magnetism. Rabi coined the term nuclear resonance magnetic.

- -In 1946 Felix Bloch at Stanford and Edward Purcell at Harvard independently described NMR in a solid. They shared the 1952 Nobel Prize in physics for this work.

- -Bloch continued extensive studies with the NMR of water, thereby laying the groundwork for later developments that led to MRI

- . As a theoretical physicist, Bloch proposed some novel properties for the atomic nucleus, including that the nucleus behaves like a **small magnet**. He described this nuclear magnetism by what are now called the **Bloch equations**.

- **Bloch's equations** explain that a nucleus, because it spins on an imaginary axis, has an associated magnetic field. This field is called a **magnetic moment**. Nucleons that have charge (e.g., protons) and that spin have even stronger magnetic fields

The Bloch equations

- The Bloch equations are a set of coupled differential equations which can be used to describe the behavior of a magnetization vector under any conditions. When properly integrated, the Bloch equations will yield the X', Y', and Z components of magnetization as a function of time

Spin, moment

- All nuclei have spin – multiples of ½
- Combined with charge ➔ moment
- Nucleus with odd spin acts like a small dipole magnet
- If nucleus has S spin states, the moment (magnet) has $2S+1$ stable states in an external magnetic field
- Hydrogen (proton): $S = ½$ ➔ 2 states

- ✓ **-Experimental verification for the Bloch equations did not come until the early 1950s.**
- ✓**By 1960 several companies were producing analytical instruments called NMR spectrometers.**
- ✓**-During the 1960s and 1970s, NMR spectroscopy became widely used in academic and industrial chemistry research.**
- ✓**-Such use of NMR enabled investigators to determine the molecular configuration of a material from the analysis of its NMR spectrum**

❑Damadian and Lauterbur

❑-In the late 1960s engineer-physician Raymond Damadian, while working with NMR spectroscopy, showed that malignant tissue has a different NMR spectrum from normal tissue.

❑ -He showed that the parameters associated with NMR

(i.e., proton density, spin lattice relaxation time, and spin-spin relaxation time) differ between normal and malignant Tissue.

❑-Damadian produced a crude NMR image of a rat tumor in 1974 and the first body image in 1976. That image took almost 4 hours to produce.

❑-In 2003 Lauterbur and Mansfield shared the Nobel Prize in physiology and medicine for their discoveries concerning magnetic resonance imaging.

❑. In fact, a large number of scientists made significant contributions to the early development of MRI

Why Magnetic Resonance Imaging?

- When a plain radiograph of the abdomen is placed on a view box for interpretation, what can be seen?

- Not much. The image is gray and flat and shows little detail.

- A conventional tomogram or an angiogram may be done to improve

image contrast.

Contrast Resolution

- **If such an image is unsatisfactory, what else can be done?**

A computed tomography (CT) image can be requested. The principal advantage of CT imaging over radiographic imaging is superior

- **contrast resolution,** the ability to image differences among low-contrast tissues.

Contrast resolution allows visualization of soft tissue with similar characteristics, such as **liver–spleen or white matter–gray matter**

- The spatial resolution of a CT image is worse than that of radiographic imaging Because it is digital and limited by pixel size. Likewise,

- The spatial resolution of MRI is worse than that of radiography. However, the contrast resolution is even better with MRI than with CT.

- **Contrast resolution is the principal advantage of MRI.**

TABLE 1-1 Approximate Spatial and Contrast Resolution Characteristics of Several Medical Imaging Systems

	Nuclear Medicine	Ultrasound	Radiography	Computed Tomography	Magnetic Resonance Imaging
Spatial resolution (mm)	5	2	0.05	0.25	0.25
Spatial resolution (lp/mm)	0.1	0.25	10	2	2
Contrast resolution (mm at 0.5% difference)	20	10	10	4	1

Spatial Resolution

- **Spatial resolution :** refers to the ability to identify an object, usually a small, dense object like a metal **fragmen**t or **microcalcificatio**n, as separate and distinct from another object.
- Table 1-1 shows representative values of spatial resolution and contrast resolution for various medical imaging devices
- In x-ray imaging, spatial resolution is principally a function of the geometry of the system.

  Two important geometric considerations include
- focal spot size
- source-to-image receptor distance(SID).

- In x-ray imaging, scatter radiation limits the contrast resolution.
- X-ray beam collimation and the use of radiographic grids reduce scatter radiation and therefore improve contrast resolution.
- تعمل موازاة حزمة الأشعة السينية واستخدام شبكات التصوير الشعاعي على تقليل الإشعاع المستطار وبالتالي تحسين دقة التباين.

- - **CT** has superior contrast resolution compared to **radiography** because it uses a finely collimated(موازة بدقه) X-ray beam, which results in reduced scatter radiation.
- -In x-ray imaging, the x-ray attenuation coefficient (μ) determines the differential x-ray absorption in body tissues.
- -the x-ray attenuation coefficient depends on the energy of the x-ray beam (E) and the atomic number (Z)of the tissue being imaged.
- -The basis for the MR image is different. It is a function of several intrinsic NMR characteristics of the tissue being imaged.
- -The three most important tissue characteristics are

I. -proton density (PD)

II. -spin-lattice relaxation time(T1)

III. - spin-spin relaxation time (T2)

- **Secondary characteristics** include: flow, magnetic susceptibility,

paramagnetism, and chemical shift.

There are many parameters to select in the production of an MR image:

- 1-The time sequence of energizing RF emissions (RF pulses)
- 2- gradient magnetic fields determines the contrast resolution.

The principal pulse sequences are :

- partial saturation
- inversion recovery
- spin echo
- gradient echo
- and echo planar.

Multiplanar Imaging

- An additional advantage to MRI is the ability to obtain
- -direct transverse,
- -sagittal
- -coronal
- - oblique plane images

- Conventional radiographs show superimposed anatomy regardless of the plane of the image.
- In CT imaging, sagittal and coronal images are reconstructed either from a set of contiguous images or directly from the volumetric data of spiral CT.

- With MRI, a large data set is acquired during a single imaging sequence from which any anatomical plane can be reconstructed

- **Viewing images obtained from various anatomical planes requires a different kind of knowledge on the part of physicians and technologists.**

- **Except for CT images, most x-ray images are parallel to the long axis of the body. The MRI interpreter may view anatomical planes that have not been imaged before.**

- **The required interpretive skills come with experience.**

- **When students enroll in a radiologic technology program, the curriculum focuses on technique selection and positioning. Patient positioning in radiography is important to ensure that the structure being imaged is parallel and close to the image receptor.**

- **MR images are directly available as projections in any plane, when the patient is properly positioned at the magnet isocenter and with intended anatomy at the sensitive region of the RF coil.**

No Ionizing Radiation

- -Another advantage of MRI over x-ray imaging is that MRI does not require ionizing radiation. This lack of ionizing radiation has been effectively used to promote the safety of MRI to the medical community and public.

- -MRI uses RF electromagnetic radiation and magnetic fields, which do not cause ionization , and therefore do not have the associated potentially harmful effects of ionizing radiation.

- -Some bio effects of RF and magnetic fields are known to exist, but the MRI systems are carefully designed to ensure that the levels reached are not high enough to cause harm and none of the biological effects associated with MRI have been linked to the induction of malignant disease

Radiologist

- There will always be a need for radiologists trained in MRI to read the magnetic resonance images. A radiologist is a medical doctor that has specialized in the field of radiology. The need is expected to grow so much that there will be and increased use of Radiology Practitioner Assistants and Radiology Physician Assistants.
- An MRI technologist is an individual that operates the MRI scanner to obtain the images that a radiologist prescribes. Based on the number of current MRI systems, it is estimated that there will be a constant need for over 1000 MRI technologists per year. A good resource for MRI technologists is the Society for Magnetic Resonance Technologists (SMRT).

Tomographic Imaging

- This computer based teaching package will provide you with an understanding of the principles of MRI form both the microscopic, macroscopic, and imaging system perspective.
- Let's begin with a pictorial introduction to some basic MRI. Magnetic resonance started out as a tomographic imaging modality for producing NMR images of a slice through the human body.
- Each slice had a thickness (Thk). This form of imaging is in some respects equivalent to cutting off the anatomy above the slice and below the slice. The slice is said to be composed of several volume elements or voxels. The volume of a voxel is approximately 2 mm3.
- The magnetic resonance image is composed of several picture elements called pixels. The intensity of a pixel is proportional to the NMR signal intensity of the contents of the corresponding volume element or voxel of the object being imaged.

A computerized X-ray imaging procedure in which a narrow beam of X-rays is aimed at a patient and quickly rotated around the body, producing signals that are processed by the machine’s computer to generate cross-sectional images—or “slices”—of the body.

These slices are called tomographic images and contain more detailed information about the internal organs than conventional X-rays

- Magnetic resonance imaging is based on the absorption and emission of energy in the radio frequency range of the electromagnetic spectrum. It is clear from the attenuation spectrum of the human body why x-rays are used, but why did it take so long to develop imaging with radio waves, especially with health concerns associated with ionizing radiation such as x-rays?
- Many scientists were taught that you can not image objects smaller than the wavelength of the energy being used to image. MRI gets around this limitation by producing images based on spatial variations in the phase and frequency of the radio frequency energy being absorbed and emitted by the imaged object.

Microscopic Property Responsible for MRI

- The human body is primarily fat and water. Fat and water have many hydrogen atoms which make the human body approximately 63% hydrogen atoms.
- Hydrogen nuclei have an NMR signal. For these reasons magnetic resonance imaging primarily images the NMR signal from the hydrogen nuclei.
- Each voxel of an image of the human body contains one or more tissues. For example here is a voxel with one tissue inside.
- Zooming in on the voxel reveals cells. Within each cell there are water molecules. Here are some of the water molecules. Each water molecule has one oxygen and two hydrogen atoms. If we zoom into one of the hydrogens past the electron cloud we see a nucleus comprised of a single proton. The proton possesses a property called spin which:
- 1. can be thought of as a small magnetic field, and
- 2. will cause the nucleus to produce an NMR signal.

- Are all nuclei have possess the property called spin ?

Units Review

- **Before you can begin learning about MRI, you must be versed in the language of MRI. MRI scientists and clinicians use a set of units when describing temperature, energy, frequency, etc. Please review these units before advancing to subsequent chapters in this text.**
- **Units of time are seconds (s).**
- **Angles are reported in degrees (°) and in radians (rad). There are 2π radians in 360°.**
- **The absolute temperature scale in Kelvin (K) is used in MRI. The Kelvin temperature scale is equal to the Celsius scale reading plus 273.15. 0 K is characterized by the absence of molecular motion. There are no degrees in the Kelvin temperature unit.**
- **Magnetic field strength (B) is measured in Tesla (T). The earth's magnetic field in Rochester, New York is approximately 5x10^-5 T.**
- **The unit of energy (E) is the Joule (J). In MRI one often depicts the relative energy of a particle using an energy level diagram.**
- **The frequency of electromagnetic radiation may be reported in cycles per second or radians per second.**
- **Frequency in cycles per second (Hz) have units of inverse seconds (s-1) and are given the symbols ν or f. Frequencies represented in radians per second (rad/s) are given the symbol ω. Radians tend to be used more to describe periodic circular motions. The conversion between Hz and rad/s is easy to remember. There are 2π radians in a circle or cycle, therefore**

  2π rad/s = 1 Hz = 1 s-1.

- **Power is the energy consumed per time and has units of Watts (W).**
- **Finally, it is common in science to use prefixes before units to indicate a power of ten. For example, 0.005 seconds can be written as 5x10-3 s or as 5 ms. The m implies 10^-3. The animation window contains a table of prefixes for powers of ten.**

ولأنه من الضروري أن تتوافق شدة المجال المغناطيسي مع الأمواج الراديوية ، سميت هذه الظاهرة بالرنين المغناطيسي النووي ؛ واستخدم التعبير " نووي " لأن أنوية الذرات فقط هي التي تتفاعل ، بينما استخدم التعبير " مغناطيسي " لأنها حدثت في مجال مغناطيسي ، أمّا كلمة " رنين " فجاءت بسبب الاعتماد المتبادل بين قوة المجال والأمواج . والحقيقة هي أن العزم المغناطيسي للأنوية يتفاعل مع المجال المغناطيسي الخارجي المؤثر على الأنوية ، وعندما تتساوى طاقة الأمواج الراديوية مع فرق الطاقة الناتج عن هذا التفاعل يحدث إمتصاص كلي لطاقة الأمواج الراديوية وهذا ما يسمى بالرنين .