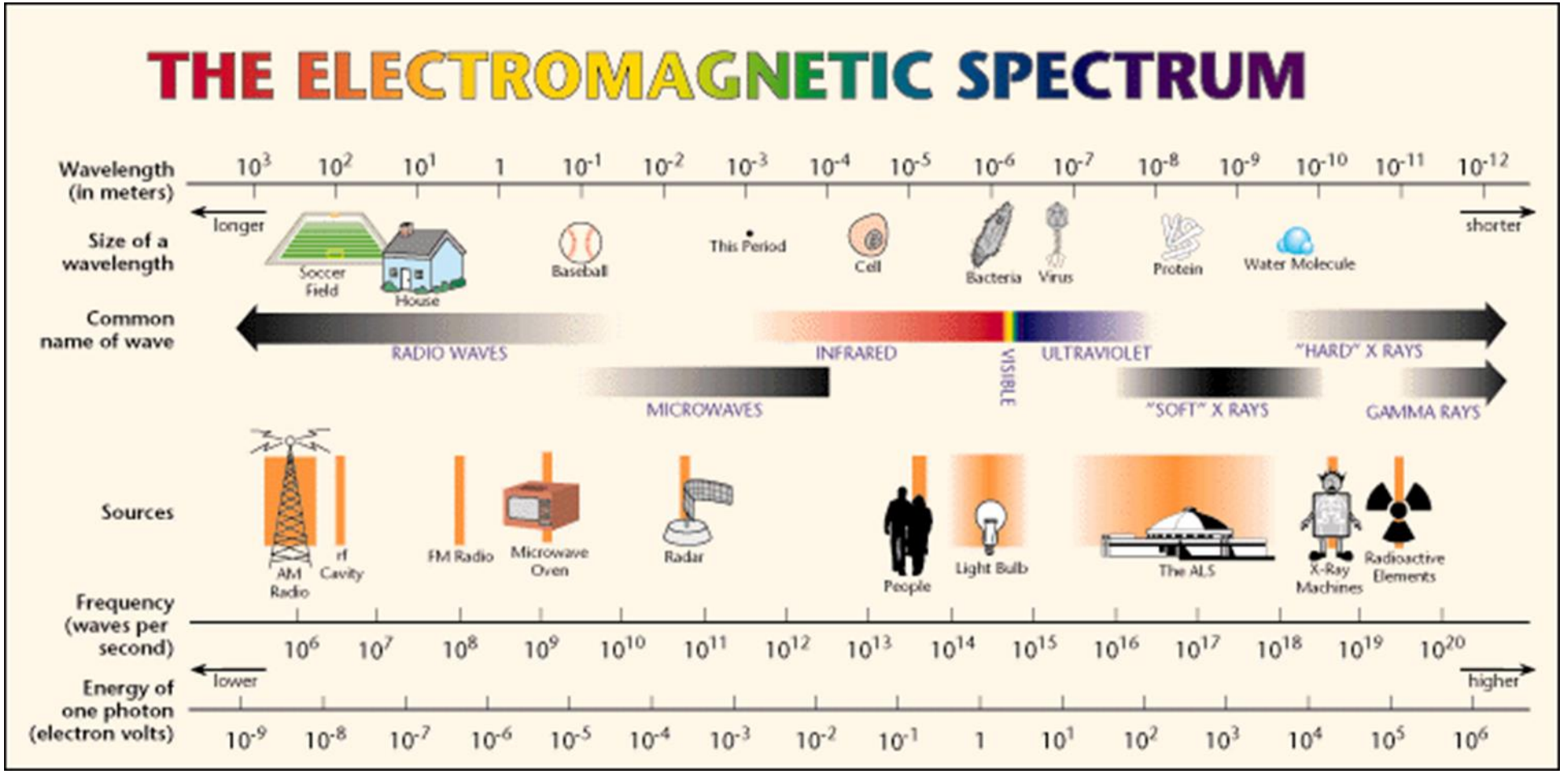
EE434
Biomedical Signal Processing
Lecture # 8

Introduction to Medical Imaging Modalities:

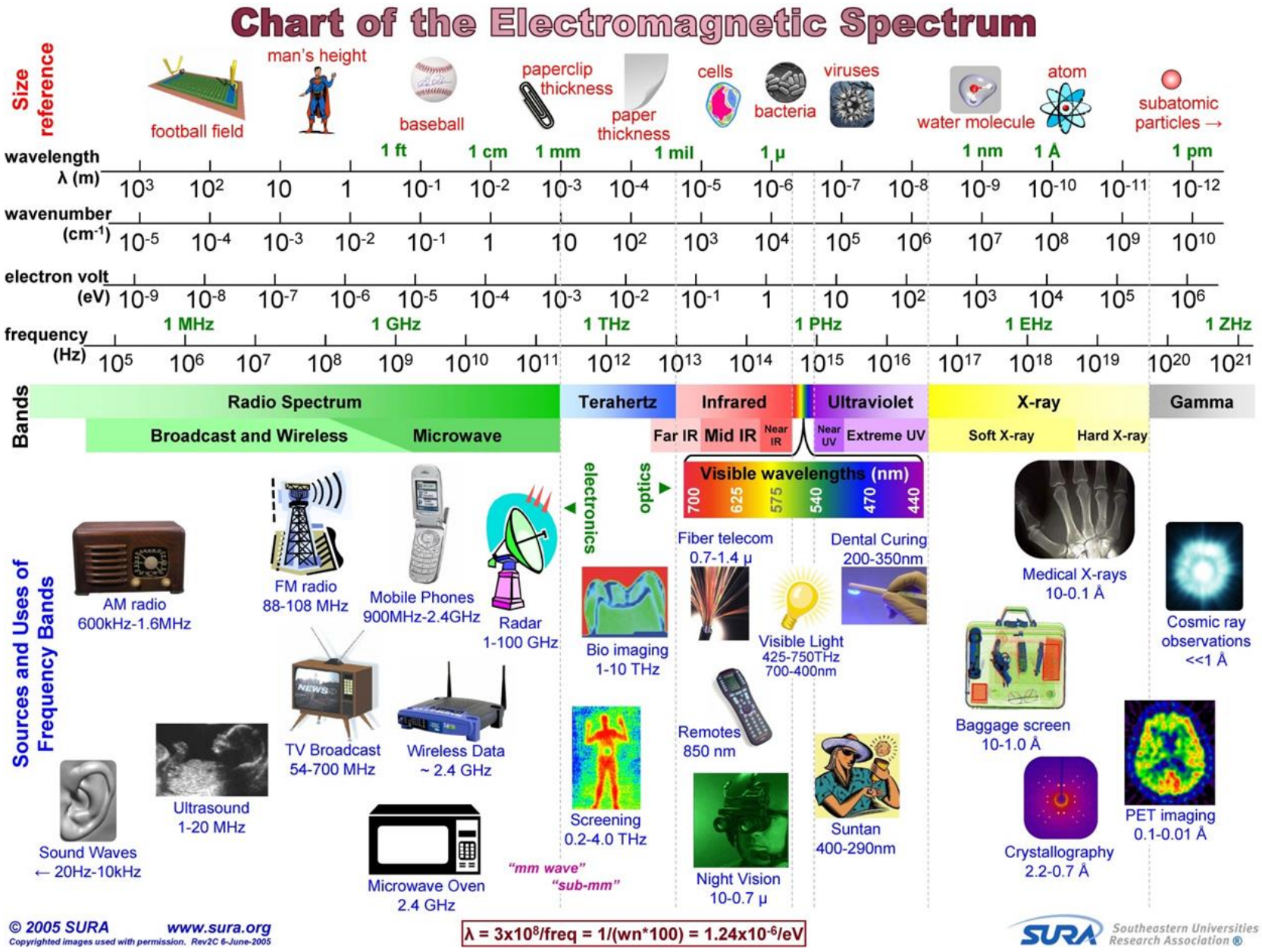
MRI, CT, PET, SPECT, Ultrasound imaging, …

The Electromagnetic Spectrum



The ***electromagnetic spectrum*** is the range of all possible frequencies of electromagnetic radiation.

The Electromagnetic Spectrum

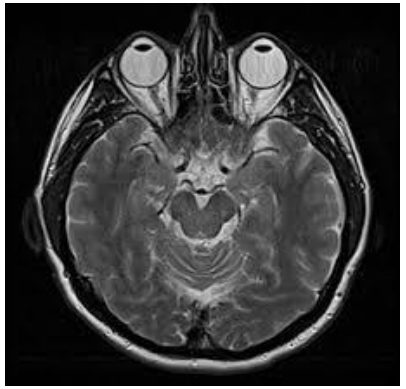
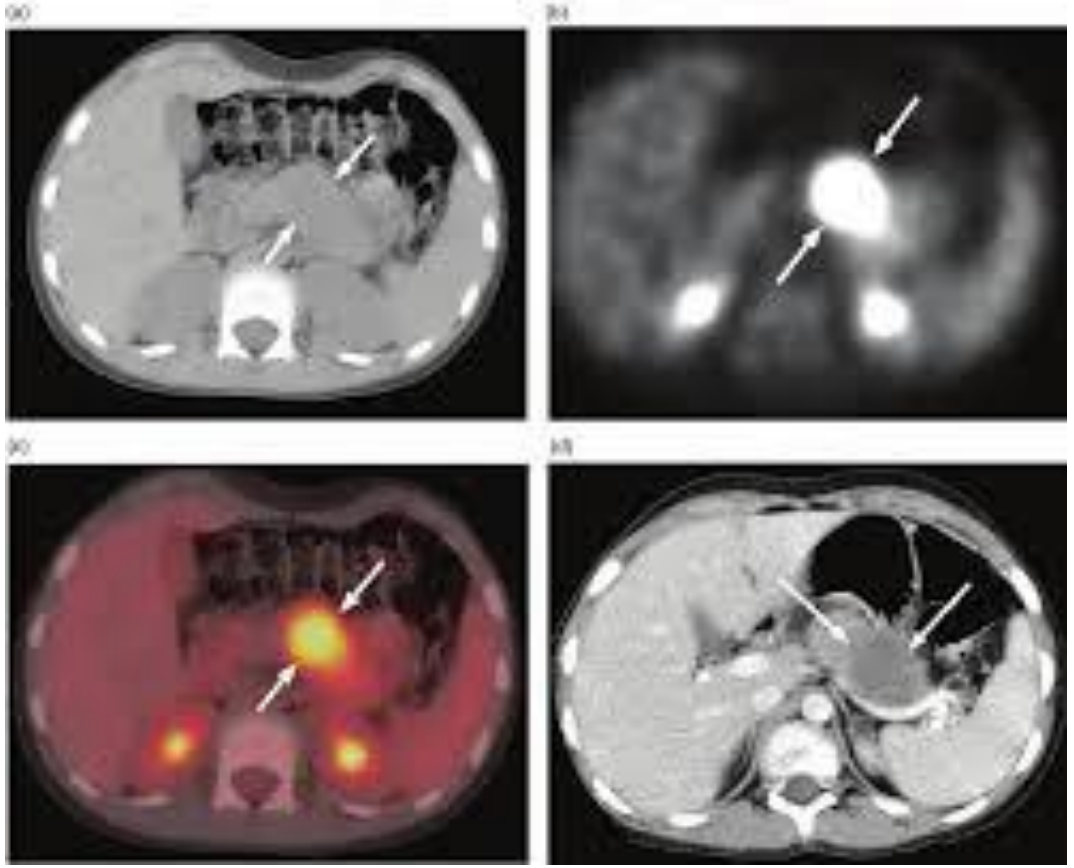
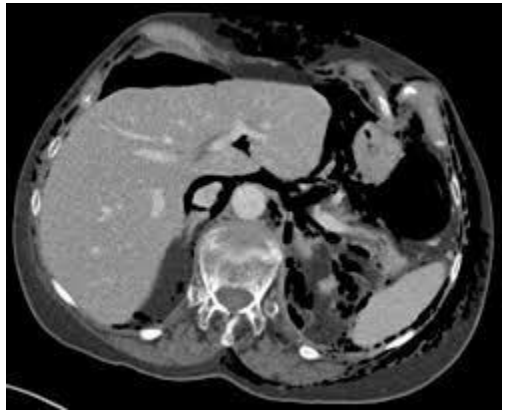
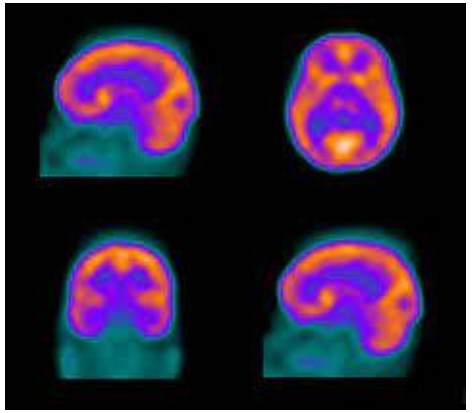


Medical Imaging Modalities

- **Medical imaging modalities** help to visualize inside the human body for diagnostic and treatment purposes without the need for surgery or other invasive procedures.
- In terms of diagnosis, common imaging types include:
  - CT (Computer Tomography)
  - MRI (Magnetic Resonance Imaging)
  - Ultrasound
  - X-ray
  - Nuclear medicine imaging (including positron-emission tomography (PET)).

Medical Imaging Modalities

- Each modality works different to create images of what's going on inside the body. Let's look at them a little closer.

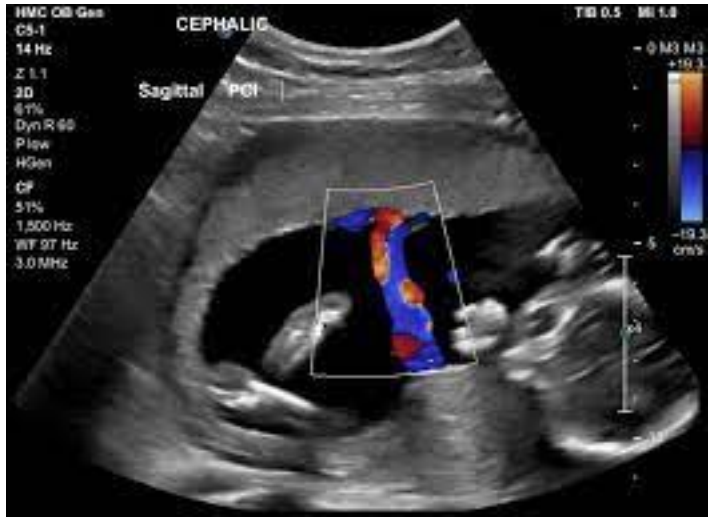






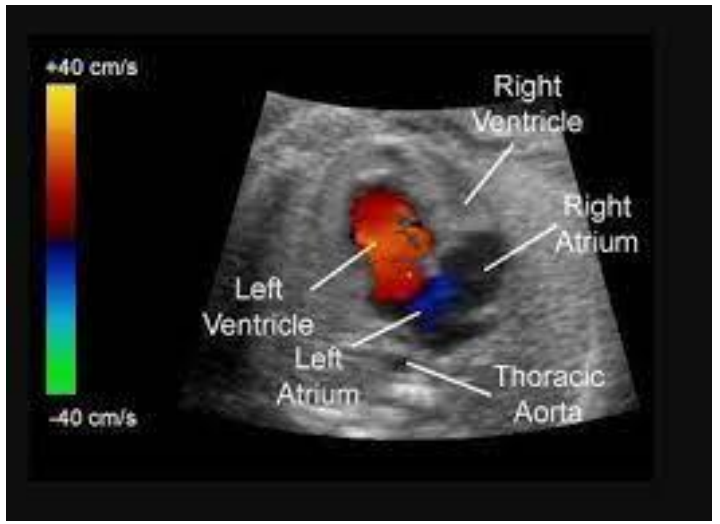
Ultrasound

- **Ultrasound** is a typically non-invasive and safe form of medical imaging that has a wide range of applications.

- **Ultrasound** uses sound waves rather than ionising radiation. High-frequency sound waves are transmitted from a probe to the body via conducting gel. Those waves then bounce back when they hit the different structures within the body, creating a real-time image.

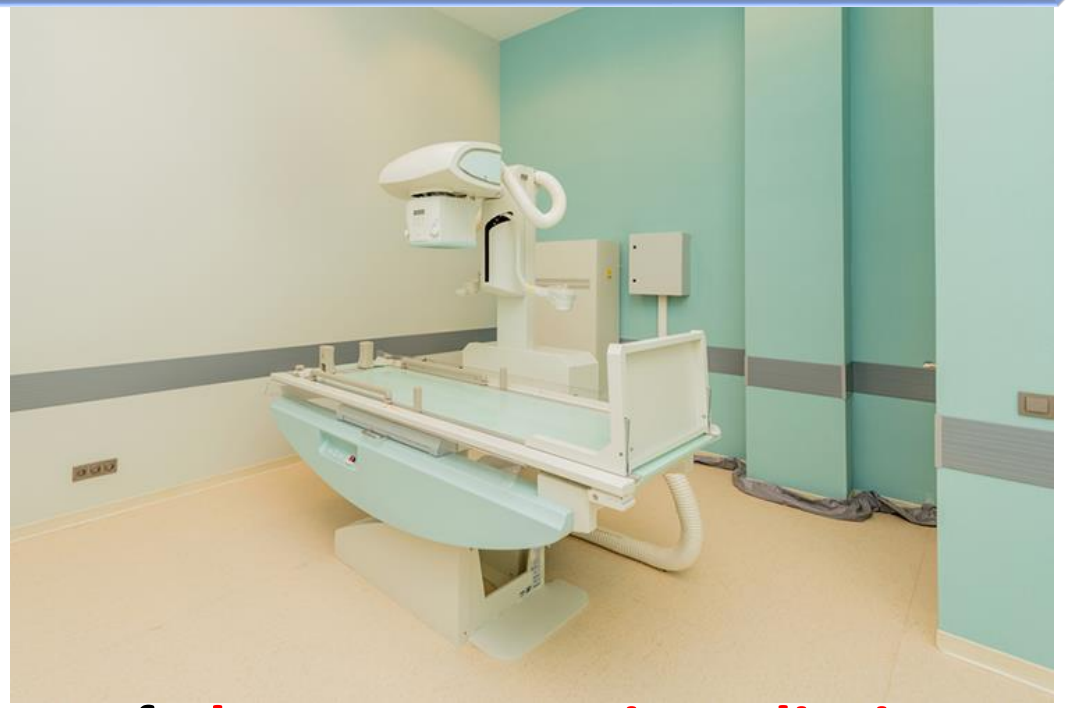
- Another type of **ultrasound** commonly used is the '**Doppler**', which allows the blood flow through the arteries and veins to be visualised
- Due to the minimal risk associated with Ultrasound imaging, it's the first choice for viewing the fetus during pregnancy.





- However, as its applications are so wide, it tends to be the first port of call for many patients. Ultrasound imaging can be used to diagnose conditions in other areas of the body, including:
  - Abdomen
  - Pelvis
  - Blood vessels
  - Breasts
  - Kidneys
  - Muscles
  - Bones
  - Joints.

X-ray Imaging



- **X-ray imaging** is the oldest but one of the most frequently used imaging types.

- Discovered back in 1895, X-rays are a form of **electromagnetic radiation**. X-rays work on a wavelength and frequency that we're unable to see with the naked, human eye. However, they can penetrate through the skin to create a picture of what's going on beneath.

X-ray Imaging

- While typically used for diagnosing issues affecting the skeletal system, **X-rays** can also be used to detect other issues such as breast cancer (through **mammography**) and digestive issues (through barium swallows and enemas).
- **X-rays** are widely used as they are quick and relatively easy for the patient to endure. However, there are risks associated with the use of radiation for **X-ray imaging**.

X-ray Imaging

- Every time a patient undergoes an **X-ray**, they receive a dose of ionizing radiation. This may go on to cause issues such as:
  - Slightly increased risk of cancer later in life
  - Cataracts
  - Skin reddening
  - Hair loss
  - Disturbance in the growth of an embryo or fetus in a pregnant patient
  - A reaction to intravenously injected contrast agents or dyes that are used to assist with visualization.

Computed Tomography (CT)

- **Computed tomography (CT)** (also known as **computed axial tomography (CAT)**) uses **X-rays** to produce cross-sectional images of the body.

Computed Tomography (CT)

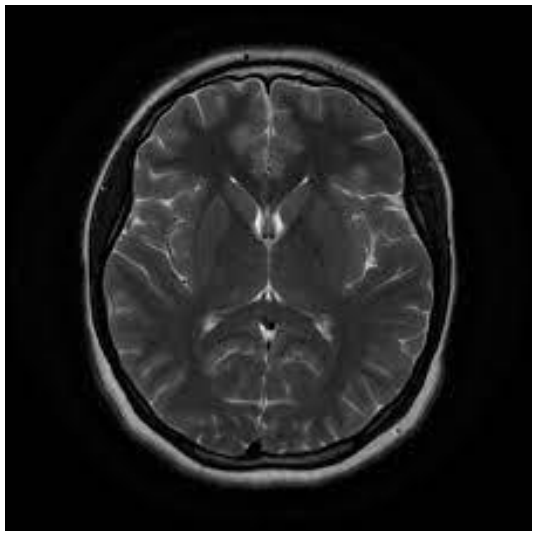
- The **CT scanner** has a large circular opening so that the patient can lie on a motorized table.
- An **X-ray** source and a detector then rotate around the patient, producing a narrow 'fan-shaped' beam of **X-rays**.
- These **X-rays** pass through sections of the patient's body in order to create 'snapshots', which are then collated into one or multiple images of the internal organs and issues.

Computed Tomography (CT)

- **CT scans** provide greater clarity than conventional X-rays, producing more detailed images of the internal organs, bones, soft tissue and blood vessels within the body.
- The benefits of using **CT scans** far exceed the risks, which (like with **X-rays**) include an increased risk of cancer, harm to an unborn child or a reaction to the contrast agent or dye used. In many cases, the use of a **CT scan** prevents the need for exploratory surgery.
- It is crucial that when scanning children, the radiation dose is lowered

Magnetic Resonance Imaging (MRI)

- **Magnetic resonance imaging (MRI)** creates diagnostic images without using harmful radiation



Magnetic Resonance Imaging (MRI)

- **MRI** uses a strong magnetic field and radio waves to generate detailed images of organs, soft tissues, bones, ligaments and cartilage. It is commonly used to examine internal body structures in order to assess:
  - Brain and spinal cord abnormalities
  - Breast, prostate, liver and other abnormalities
  - Joint abnormalities or injuries
  - Spinal injuries
  - Tendon and ligament tears

Magnetic Resonance Imaging (MRI)

- Heart structure and function
- Areas of activation in the brain
- Blood flow through blood vessels and arteries
- Chemical composition of tissues
- Organs in the pelvis, chest and abdomen (e.g. heart, liver, kidney, spleen).

How it works:

- The human body is made mostly of water, and each water molecule contains a hydrogen nucleus (proton).
- An MRI scanner uses a strong magnetic field to force the protons to align to that field.
- A radio frequency is then applied, which stimulates the protons and spins them out of equilibrium.
- When the frequency is turned off, the protons return to their original alignment, releasing energy that is detected by the MRI sensors

Magnetic Resonance Imaging (MRI)

- Protons in different body tissues return to their normal alignment at different rates, allowing the MRI to distinguish between various types of tissue and identify any abnormalities.
- The way in which the molecules ‘flip’ and return to their normal spin alignment is recorded and processed to form an image.

- MRI doesn’t use harmful ionizing radiation. However, there are other disadvantages associated with its use.
- As strong magnets are used, metal implants such as pacemakers and implantable cardioverter-defibrillators (ICDs) in the patient's body can be hazardous as they may be moved or heated up within the magnetic field.
- There have been several reported cases of patients with pacemakers dying through the use of MRI.

- Other disadvantages associated with MRI include:
  - The loud noise from the scanner, which necessitates the need for ear protection
  - Length of the procedure
  - Magnetic objects being attracted to the strong magnetic field and potentially becoming dangerous projectiles (for this reason, objects entering the magnetic field must be screened carefully)
  - Heating of the body
  - Adverse reactions to the contrast agent
  - Potential feelings of claustrophia
  - The need to remain still for the duration of the procedure (potentially requiring patients to be sedated).

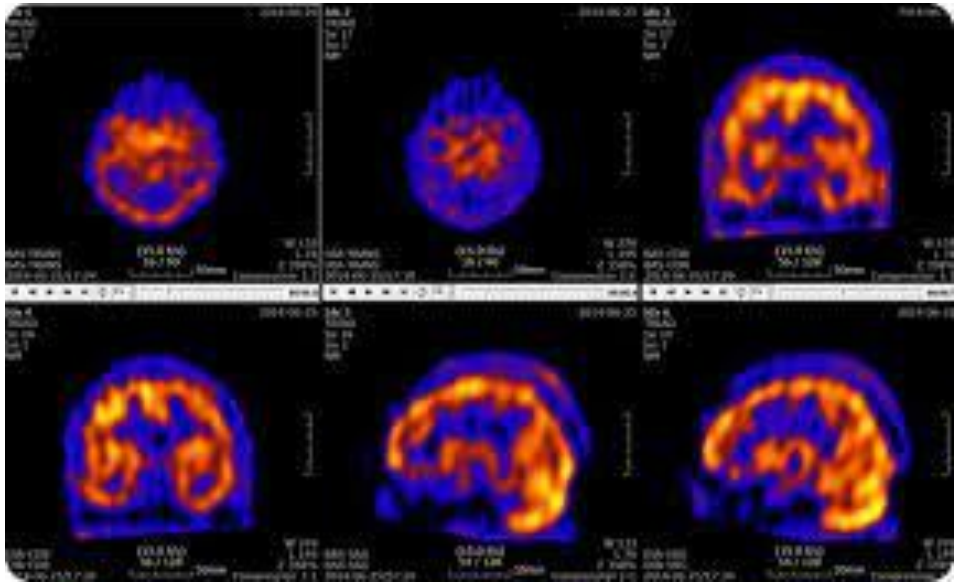
Positron Emission Tomography (PET)

- A **positron emission tomography (PET)** scan involves injecting, swallowing or inhaling a radioactive agent known as tracer. The patient then lies in a PET scanner, a large doughnut-like structure that detects gamma rays from the tracer and converts them into images. Bright spots on the image indicate higher chemical activity, potentially caused by a disease

Positron Emission Tomography (PET)

- **PET** scans are used to diagnose conditions such as tumors, heart disease and brain disorders. They can be used to assess the entire body or one specific area.
- While PET scans are generally painless for the patient, they involve exposure to ionizing radiation.
- Other disadvantages include the risk of adverse reactions to the radioactive material and potential feelings of claustrophobia for the patient

- A **SPECT scan** is a type of nuclear imaging test which uses a radioactive substance and a special camera to create 3-D images.



- While imaging tests such as **X-rays** can show what the structures inside your body look like, a SPECT scan produces images that show how your organs work. For instance, a SPECT scan can show how blood flows to your heart or what areas of your brain are more active or less active.

An Example: PET vs MRI