NDEin Biomedical Engineering

Aditya Bhagwat, Pradeep Kumar
Pradeep Kumar, Phone - +91 8793783078; +91 8380063857
Email – pradeep.kumar@iqs-ndt.org

Abstract

Introduction –

Biomedical Engineering (BME) is an interdisciplinary field, marking the conjunction of Medical and Engineering disciplines.

It combines the design and problem solving skills of engineering with medical and biological sciences to advance health care treatment, including diagnosis, monitoring, and therapy.

Role of NDE in Biomedical Engineering –

Throughout history, a persistent goal of medicine has been the development of procedures for determining the basic cause of a patient's distress. As a result, the search for tools capable of ''looking into'' the human organism with minimal harm to the patient has always been considered important. Today, modern imaging devices, based on fundamental concepts in physical science (e.g., x-ray and nuclear physics, optics, acoustics, etc.) and incorporating the latest innovations in computer technology and data processing techniques, have not only proved extremely useful in patient care, they have revolutionized health care. NDE plays a pivotal role in Biomedical Engineering. Various NDE Techniques have been used for the analysis of human bodies to diagnose the diseases. They include Computer Tomography (CT) scans, Magnetic Resonance Imaging (MRI) and Diagnostic Ultrasonic Imaging.

BME, in India, is largely connected with the sales branch of the industry, rather than the core technical part of the industry, to which it is actually related. Outside India, however, BM Engineers are perceived as Engineers and not as auxiliary technical assistants.

Make In India campaign is promising to achieve the very same goal, as a lot of BM engineers would be required to handle the technical requirements of the NDE machinery manufactured in India.

NDE Techniques in BME –

NDE in BME is focused on imaging instruments and methods. It involves the following two methods –

Radiation Imaging
Medical Imaging

Radiation imaging –

Ionizing radiation (i.e., radiation capable of producing ion pairs) is either (a) radiation that is introduced into the body, thereby making the patient the ''source'' of radiation emissions, or (b) externally produced radiation, which passes through the patient and is detected by radiation-sensitive devices ''behind'' the patient.

During cellular or organ system function studies, gamma or x-rays are emitted and detected outside the patient, providing physiological (rate of decay or ''washout'') and anatomical (imaging) information.

Radiation that is introduced into the body, thereby making the patient the ''source'' of radiation emissions

In this technique, the radiation source, known as radiopharmaceutical, is injected into the patient's body. Thus, the patient's body becomes a source of radiation. This radiation is then imaged by radiation imaging devices specifically meant for the purpose. The injection can be done by swallowing, breathing or by direct injection into the vein.

The term radiopharmaceutical consists of two parts - the radioactive part and the pharmaceutical part. The radioisotopes commonly used are Technetium 99m, but other radioisotopes such as iodine 123, indium 111 and gallium 67 are also used. The pharmaceutical part can be a few atoms or a complex molecule that helps take the radioactive part to the area of the body being studied. It would seem to be quite unsafe as the radioactive part is injected inside the human body. But its exposure is the same as that of regular chest x-ray scan (About 140.5 keV gamma rays). Its physical half-life (6 hours) and its biological half-life of 1 day (in terms of human activity and metabolism) allows for scanning procedures which collect data rapidly, but keep total patient radiation exposure low. This technique involves the following devices for imaging –

Scintillation Detectors:

Certain materials, for example, zinc sulfide and sodium iodide, have the property of emitting a flash of light or scintillation when struck by ionizing radiation. The amount of light emitted is, over a wide range, proportional to the energy expended by the particle in this material. When the scintillator material is placed next to the sensitive surface of an electronic device called a photomultiplier, the light from the scintillator is then converted into a series of small electrical pulses whose height is directly proportional to the energy of the incident gamma ray. These electrical pulses can then be amplified and processed in such a way as to provide the operator with information regarding the amount and nature of the radioactivity striking the scintillation detector. Thus scintillators may be used for diagnostic purposes to determine the amount and/or distribution of radionuclides in one or more organs of a patient.

As shown in Figure -1, a basic scintillation detection system consists of -

A detector, which usually includes the scintillation crystal, photomultiplier tubes, and preamplifier; Signal processing equipment such as the linear amplifier and the single-channel pulse analyzer; and Data display units such as the scaler, scanner, and oscilloscope. Once the radioactive event is detected by the crystal and an appropriate pulse is generated by the photomultiplier circuitry, the resulting voltage pulses are still very small. To avoid any serious loss of information caused by distortion from unwanted signals (such as noise) and to provide a strong enough signal to be processed and displayed, the amplifier is used to increase the amplitude of the pulses by a constant factor. This process is called linear amplification.

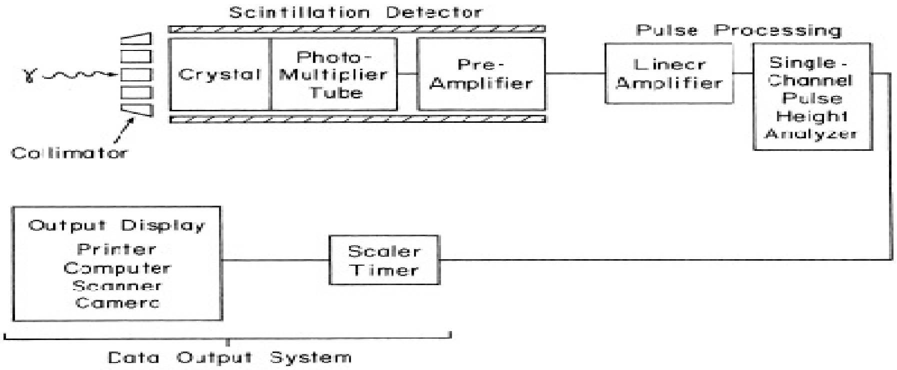

Figure 1 Basic Scintillation Detection System

Gamma Camera:

The operation of the basic gamma camera is illustrated in Figure 2. The detector of the gamma camera is placed over the organ to be scanned. To localize the radiation from a given point in the organ and send it to an equivalent point on the detector, a collimator is placed over the base of the scintillation crystal. Since gamma rays cannot be ‘‘bent,’’ another technique must be used to selectively block those gamma rays that, if allowed to continue on their straight-line path, would strike the detector at sites completely unrelated to their points of origin in the subject. This process of selective interference is accomplished by the collimator. To prevent unwanted off-axis gamma rays from striking the crystal, collimators usually contain a large number of narrow parallel apertures made of heavy-metal absorbers.

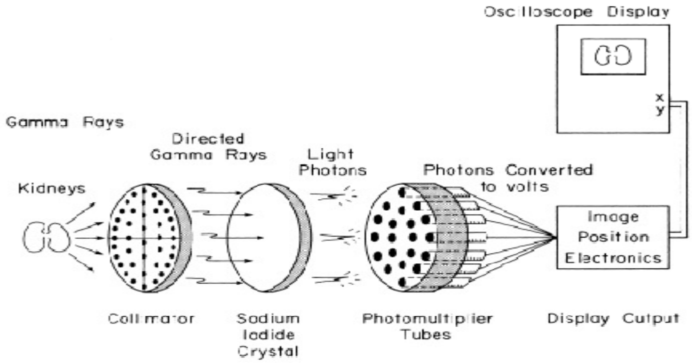

Figure 2 Basic Elements of a Gamma Camera

Consider the multi-hole collimator illustrated in Figure 3(a). In this case, the collimator consists of a flat lead plate through which narrow holes are drilled. As can be seen, only a gamma event occurring directly under each hole will penetrate the collimator, and it will be represented at only one location on the face of the crystal. If this gamma event occurred much further away from the collimator, such as in region Y, then it would be represented by more than one location on the face of the crystal. When this occurs, the resolution, which may be defined as the ability of the detector to distinguish between two sources at various distances from the collimator, is greatly decreased. For the multihole collimator, then, the best resolution occurs when the area of interest is close to the collimator. Thus, as the subject is moved from point Z toward the detector, the resolution is improved. Obviously, when viewing an organ that lies beneath the surface of the skin, it becomes quite important to closely approximate its distance from the probe relative to the degree of resolution required. The pinhole collimator permits entry of only those rays aimed at its aperture. These gamma rays enter the collimator and proceed in a straight line to the crystal where they are detected in inverted spatial correspondence to their source.

When the source is located at a distance from the collimator equal to that of the pinhole to the crystal, then the source is represented on the crystal in exactly the same size as it exists. However, by proper positioning of the subject, it is possible to actually magnify or decrease the field of view of the detector. That is, as the source is moved closer to the aperture of the collimator, magnification occurs. A pinhole collimator, therefore, enlarges and inverts the image of the source located beneath it.

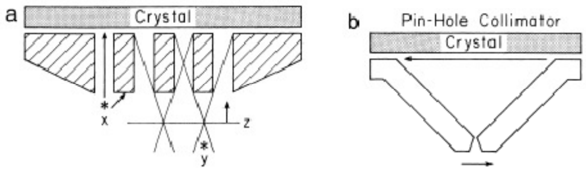

Figure 3(a) Multihole collimator used in conjunction with scintillation detector. Event x is represented at only one location in the crystal, whereas event y has multiple sites associated with its occurrence.

3(b) The pinhole collimator allows magnification and is used for viewing small organs at short rang

Positron Imaging

The positrons emitted through transformation of a radionuclide can travel only a short distance in a tissue (a few millimeters), and then are annihilated. A pair of scintillation detectors can sense positron emission by measuring the two photons in coincidence.

Annihilation coincidence detection provides a well-defined cylindrical path between the two detectors. Multihole collimators are unnecessary to define the position in a positron camera because electronic collimation accomplishes the task.

Externally produced radiation, which passes through the patient and is detected by radiation-sensitive devices ''behind'' the patient:

These radiographic imaging systems rely on the differential attenuation of x-rays to produce an image.

All x-ray imaging systems consist of an x-ray source, a collimator, and an x-ray detector. Diagnostic medical x-ray systems utilize externally generated x-rays with energies of 20–150 keV.

Using the standard film screen technique, x rays pass through the body, projecting an image of bones, organs, air spaces, and foreign bodies onto a sheet of film (see Figure 4). The ''shadow graph'' images obtained in this manner are the results of the variation in the intensity of the transmitted x-ray beam after it has passed through tissues and body fluids of different densities.

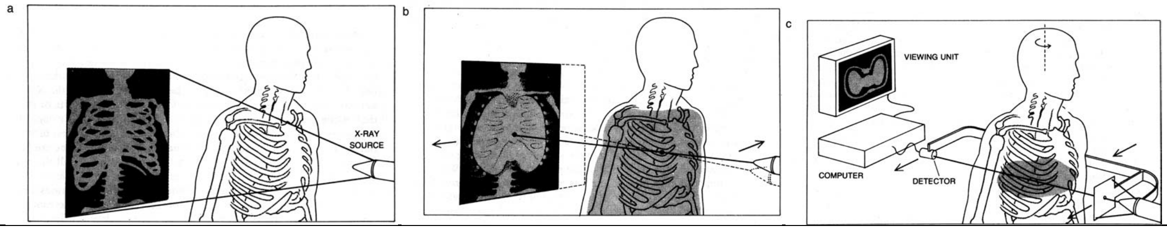

Figure 4 (a) A conventional x-ray picture is made by having the x-rays diverge from a source, pass through the body, and then fall on a sheet of photographic film.

4(b) A tomogram is made by having the x-ray source move in one direction during the exposure and the film in the other direction. In the projected image, only one plane in the body remains stationary with respect to the moving film. In the picture, all other planes in the body are blurred.

4 (c) in computerized tomography, a reconstruction from projections is made by mounting the x-ray source and an x-ray detector on a yoke and moving them past the body.

The yoke is also rotated through a series of angles around the body. Data recorded by the detector are processed by a special computer algorithm or program. The computer generates a picture on a cathode-ray screen.Since bone strongly absorbs x-rays, fractures are readily discernible by the standard radiographic technique. When this procedure is used to project three-dimensional objects into a two-dimensional plane, however, difficulties are encountered. Thus, attempts have been made to obtain shadow graphs from a number of different angles in which the internal organs appear in different relationships to one another and to introduce a medium (such as air or iodine solutions) that is either translucent or opaque to x-rays.

With the advent of plane tomography, the imaging of specific planes or cross sections within the body became possible. Here, the X-ray source is moved in one direction and the photographic film, which is placed on the opposite side of the body, is moved in the opposite direction. The result of this procedure is that, while the x-rays travel continuously changing paths through the body, each ray passes through the same point on the plane or cross section of interest throughout the exposure. Consequently, structures in the desired plane are brought sharply into focus and are displayed on film, whereas structures in all the other planes are obscured and show up only as a blur. Although this approach is better than the conventional one, it poses two important disadvantages –

1.It does not really localize a single plane since there is some error in the depth perception obtained.

2. Large contrasts in radiodensity are usually required to obtain high-quality images that are easy to interpret. In addition, x-ray doses for tomography are higher than routine radiographs, and because the exposures are longer, patient motion may degrade the image content.

Computerized tomography (CT) represents a completely different approach.

Computed tomography is the name given to the diagnostic imaging technique in which tissues of the body are digitally reconstructed from attenuated x-rays data obtained from many directions in a particular plane.

A tomographic image can be generated by following methods of coordination of movement during exposure:

(a) The patient remains stationary while the x-ray tube and the film (or detector) move in coordination. This is most widely used method.

(b) The x-ray tube remains stationary while the film (or detector) with the patient move in coordination.

(c) The film (or detector) remains stationary while x-ray tube, with the patient, moves in coordination.

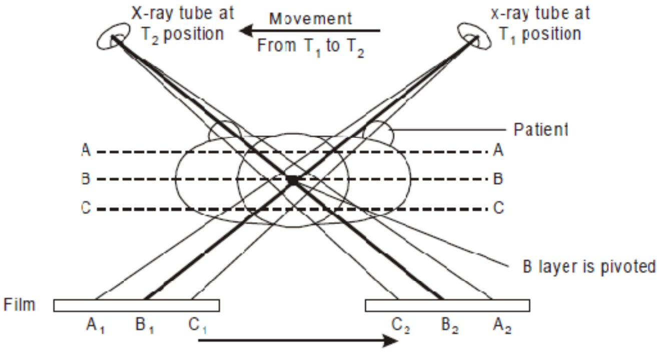

Figure 5 Principle of Tomography

The evolution of the CT Scan process is given below -
Conventional process → Spiral CT Scan →Thick Spiral CT Scan → Multi-Slice CT Scan

Magnetic Resonance Imaging (MRI) –

MRI is unique imaging method because unlike the usual method of radiography, radioisotopes and CT scanning, it does not rely on radiation. In this, protons of the nuclei of hydrogen atoms are subjected to radio frequency pulses in a strong magnetic field. The protons get thereby "excited" to higher energy level. Protons also get "relaxed" to the lower energy level on the switching off radio frequency pulses. The protons emit radio frequency signals when they move from "excited" to "relaxed" state. These radio signals can be detected by a receiver and a computer can further process the output into an image. In our body tissues, protons of hydrogen are most abundant as hydrogen atoms of water molecules (H of H2O). Hence MRI image shows difference in the water content and distribution in various body tissues. Each different type of tissues within the same region can be easily distinguished.

The components of a MRI system are –
(1) a magnet (2) gradient coils (3) a transmitter (4) a receiver (5) a computer and
(6) shin coils.

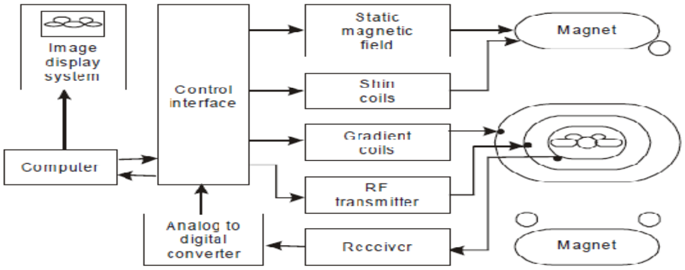

Figure 6 The Components of a MRI System

A strong magnet is provided to produce a highly uniform static magnetic field (1 to 3 Tesla) which is 10,000 to 30,000 times stronger than the earth's magnetic field. The magnet can be permanent or electromagnetic type. The magnet is a large and has cylindrical shape with a large aperture at centre to enclose the sliding table on which a patient can lie down for imaging. The gradient coils are provided to create magnetic field gradient in the tissues of the body to be imaged for spatial encoding of the signals. The transmitter operates at radio frequency to generate pulse sequence to resonate the hydrogen protons (nuclei) of the tissues. The receiver is required to detect the MRI signals emitted by nuclei of hydrogen during relaxation. The output of the receiver is linked to the computer. The computer and display system is provided to control the system operation so that images can be processed, stored, reconstructed and displayed, as and when required. Shin coils are placed at suitable places to maintain the homogeneity of the magnetic field.

Ultrasound Imaging –

The application of ultrasound in medical field is based on the sonar principle as used by bats, ships at sea and anglers with fish detectors. It is totally non invasive procedure. Acoustic waves are easily transmitted in water but they are reflected from an interface according to the change in the acoustics impedance.

Leaving bones and lungs, all tissues of our body are composed of water which can transmit acoustic waves easily. Ultrasound can be used for obtaining images of internal organs by sending high frequency sound waves into the body. The reflected sound waves (returning echoes) are recorded and processed to reconstruct real time visual images by the computer. The returning sound waves (echoes) reflect the size and shape of the organ and also indicate whether the organ is solid, fluid or something in between. Unlike x-rays, ultrasound requires no exposure to ionization radiation. It is also a real time technique that can produce a picture of blood flow as it is at the very moment of imaging.

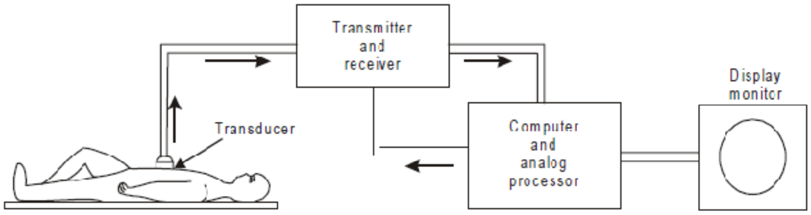

Figure 7 Schematic Block Diagram of a B-mode Ultrasound

The ultrasound image is formed from the useful information contained by the echoes of the ultrasound which are reflected back while traversing and interacting with the tissues of the body. These interactions contribute to image formation and images vary as the tissues vary themselves. It is important to have known values of acoustic impedance (z) and speed of ultrasound in the particular tissue. The acoustic impedance is a function of the elasticity and density of a particular tissue. Materials with high acoustic impedance can transmit sound faster than others.

Doppler ultrasound is based on the principle that sound reflected by a moving target like blood has a different frequency from the incident sound wave. The difference in frequencies is known as Doppler shift which is proportional to the velocity of the target. Doppler shift is the useful information with the echoes which helps in the detection of flowing blood. It also enables to quantify the velocity of the blood. It is possible to give colour coding to the doppler information and superimpose it on a real time B-mode image facility which can help in identification of blood vessels or blood vessels having abnormal flow.

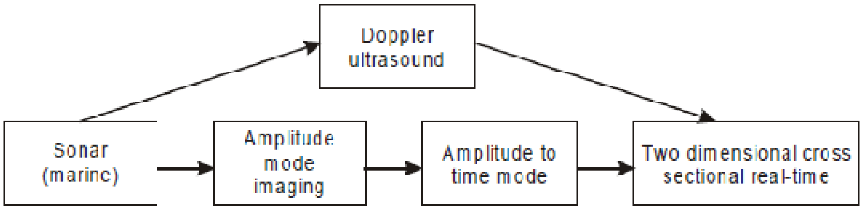

Figure 8 Evolution of Ultrasound System

Conclusion – NDE techniques are used for the same purpose in BME as in mechanical industry – to detect the disease by imaging and at times, also to cure it to some extent as in radiology. But detecting a disease is, in itself, partially curing it.

References –

Enderle_Introduction to Biomedical Engineering 2nd ed By John D. Enderle, Susan M. Blanchard, Joseph D. Bronzino
Fundamentals of Biomedical EngineeringBy G. S. Sawhney
http://patient.info/health/radionuclide-isotope-scan
http://www.insideradiology.com.au/pages/view.php?T_id=66#.Vdq8T_mqqko
http://bme.udel.edu/about/why-biomedical-engineering/
http://dels-old.nas.edu/global/About-Us