International Journal of Physics and Applications

**E-ISSN:** 2664-7583
**P-ISSN:** 2664-7575
IJOS 2023; 5(1): 38-43

[www.physicsjournal.in](http://www.physicsjournal.in)
Received: 06-01-2023
Accepted: 09-02-2023

**Wisam A Latif**
Alkarkh University of Science, Baghdad, Iraq

**Entessar Karim Hanoun**
Alkarkh University of Science, Baghdad, Iraq

**Mohammed O Kadhim**
Alkarkh University of Science, Baghdad, Iraq

**Corresponding Author:**
**Wisam A Latif**
Alkarkh University of Science, Baghdad, Iraq

# Review Article: Radiation therapy: Treatment technology and medical imaging

**Wisam A Latif, Entessar Karim Hanoun and Mohammed O Kadhim**

**DOI:** https://doi.org/10.33545/26647575.2023.v5.i1a.62

**Abstract**
In the last century, there have been significant advancements in the treatment of cancer through the use of ionizing radiation therapy. These advancements are mainly due to the progress made in medical imaging. The introduction of computed tomography (CT) has greatly improved the planning of treatment. However, CT remains the only imaging modality used for dose calculation in three dimensions, despite its limitations. More modern imaging techniques such as magnetic resonance imaging (MRI) and positron emission tomography are primarily used in the treatment-planning process. MRI, with its superior tissue contrast and resolution compared to CT, aids in tumor delineation. PET provides metabolic data along with anatomical information from CT and MRI. Clinicians can make more informed decisions about the most effective treatment options for cancer patients by analyzing and visualizing the metabolic profile, active pathways, and genetic markers of tumors. This knowledge can be used to compare different tumors and assess the heterogeneity of a specific tumor. The aim is to quickly determine the effectiveness and location of a chosen therapy. In the future, multimodality scanners such as PET/CT and PET/MR will provide the most precise information for targeting tumors in the era of the human genome.

**Keywords:** Radiation therapy, medical imaging, radiology

## Introduction

Radiation therapy, also known as radiotherapy, is a medical treatment that uses high-energy radiation to destroy or damage cancer cells in the body. Radiation therapy can be delivered using different types of radiation, such as X-rays, gamma rays, or charged particles, depending on the location and type of cancer being treated. In the past, radiation therapy was implemented using conventional techniques that delivered radiation to the tumor and surrounding tissue in a uniform dose. Conventional radiation therapy could cause more side effects because it delivered radiation to healthy tissue surrounding the tumor, increasing the risk of damage to nearby organs and tissues. However, since the late 1990s, intensity-modulated radiation therapy (IMRT) has been widely recognized as the preferred method of treatment for areas such as the head, neck, and prostate. IMRT allows for highly precise dose distributions to be delivered to the target area, resulting in improved conformality and reduced radiation exposure to surrounding normal tissues [1-4].

Advanced treatment technology and medical imaging have significantly improved the precision and accuracy of radiation therapy, particularly with the development of IMRT. This innovative approach allows more conformal distribution of the radiation dose to the target area, while reducing the exposure of nearby healthy tissue to radiation. Accurate patient setup is essential for successful treatment, and recent advancements in medical imaging have made it easier to formulate complex treatment plans and precisely locate the target area. By leveraging the benefits of IMRT, we can enhance tumor control and reduce the negative effects of radiation treatment. Target definition at the planning stage frequently relies on CT (Computed Tomography) as well as other imaging modalities including MRI and PET (Positron Emission Tomography). While therapy stage, the target and/or tumor movements can be localized using three-dimensional volumetric imaging. To further increase the geometric accuracy and precision of radiation administration, it is possible to measure and account for changes in tumor position, size, and form that occur during radiotherapy [6].

**Mammography**

Breast cancer is a prevalent health issue affecting many women in the United States, with statistics indicating that one out of eight women may develop invasive breast cancer at some point in their lives. Despite recent advancements in treatment, breast cancer remains a leading cause of cancer-related deaths among women. However, early detection is key to improving patient outcomes, as breast cancer is highly treatable when detected early. The opportunity of getting a successful therapy is almost certain when tumors are small and localized. Timely detection of serious breast tumors is critical for extending patient lifespan and reducing mortality rates. The Swedish Organized Service Screening Assessment has also demonstrated the importance of early detection in improving survival rates, [8, 9]).

The majority of cancer experts believe that mammography is currently the most effective imaging method for detecting breast cancer at an early stage. Mammography is a highly sensitive imaging technique that can detect small tumors or changes in breast tissue that may indicate the presence of cancer. Also, Mammography is a safe and non-invasive screening test that involves low doses of radiation. It is a quick and painless procedure that can be performed in a matter of minutes. Furthermore, Mammography is widely available and accessible, with screening programs and centers located in many communities around the world [8, 10].

In the US, routine mammograms are advised for all women over 40 and for at-risk women as a preventive measure. Low-energy X rays are used in mammography, a specialized radiographic examination of breast tissue. It makes it possible to spot abnormalities in the breast tissue that could be symptoms of breast cancer (usually recognizable lumps or micro-calcifications). Mammography is mostly utilized as a screening and diagnostic technique for the early identification of breast cancer, but it can similarly be used to localize questionable areas and direct needle biopsies and other treatments. It also aids in treatment monitoring because it can be used to identify and assess breast changes.

Based on how it functions, mammography can be divided into two primary categories:

1. Screening
2. Diagnostic mammography.

The purpose of mammography screening, as a preventive measure, is to detect signs of cancer in women who do not display any symptoms as illustrated in figure 1.

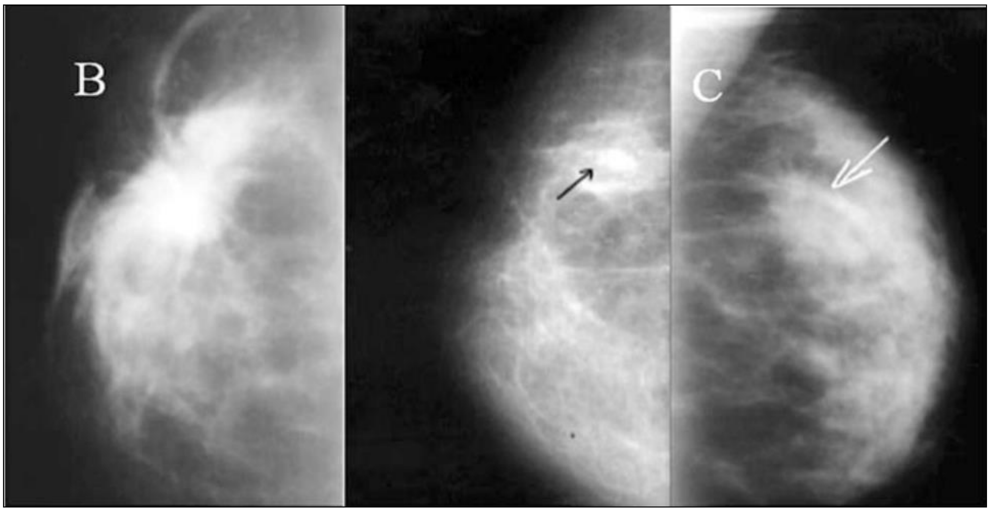


**Fig 1:** Breast cancer's mammographic characteristics, (a) undefined margins of irregular mass, (b) micro-calcifications that are clustered and (c) distorted architecture [11].

**Computed Tomography**

Each human bodily tissue responds differently to X-rays than other tissues. Quantitative differences in X-ray absorption exist between tissues. These distinctive qualities of tissues can be used for a variety of beneficial purposes. One of those crucial applications that relies on the idea that biological tissues absorb X-rays is computed tomography, or CT. Physicians can identify and treat medical disorders with CT (CAT) scanning, a noninvasive medical procedure. This method creates numerous photographs of the interior of a target body part using specialized X-ray gear and top-notch computers. Typically, 3-D images are captured. The doctors then prescribe the proper remedies after reviewing those photographs on a computer.

Sometimes referred to as a "slice," a CT (computed tomography) image shows what an object would appear if it were cut apart along a particular plane. A better comparison would be a slice from a loaf of bread, since a CT slice represents a specific thickness of the scanned object. As a result, a CT slice image is made up of voxels, which are volume elements, rather than the pixels of a typical digital image. A full, three-dimensional picture of an object can be created by collecting continuous set of CT slices, similar to how a loaf of bread can be reconstructed by assembling all of its slices. Figure 2 shows normal CT scan of the brain.

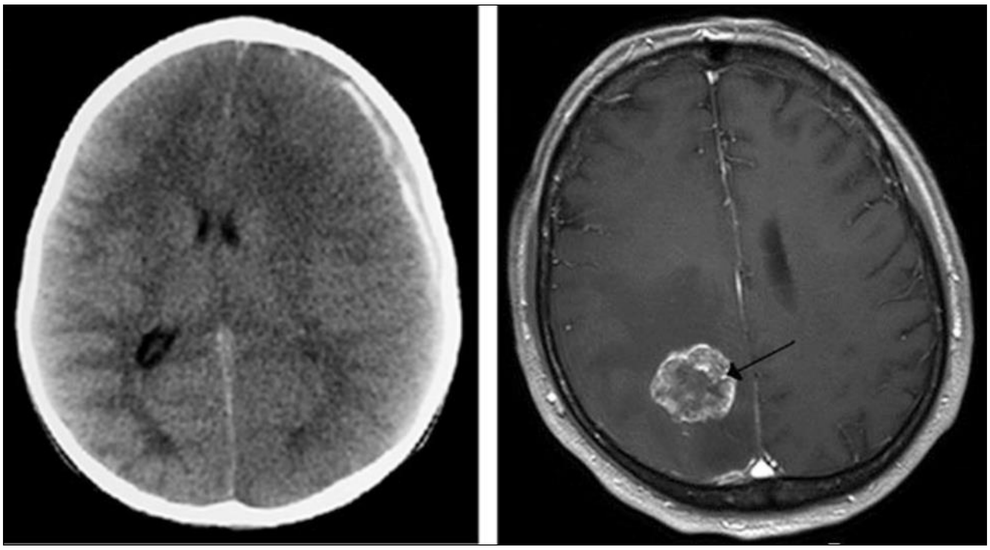

**Fig 2:** (left) normal human brain on a CT scan, (right) a tumor growing within a human brain.

During a CT scan, numerous kilo voltage (kV) X-ray beams in the shape of pencils or fans, known as photons, are directed through a specific region of the body at various angles, typically spanning over 180 degrees.

On the other side of the volume, a dosimeter is positioned to estimate the X-ray exposure it receives. This makes it possible to measure how much each beam is attenuated as it moves through the volume. It should be remembered that the beam attenuates (absorbs or scatters) when high-energy X-rays pass through tissue or other materials. Although scattering is insignificant at low energies (kV), only X-ray absorption is taken into account in CT when a kV beam is employed. A "voxel" is a three-dimensional pixel with width, height, and depth, and each component of the volume can be thought of as one. As each beam moves across the space, it will go through a variety of voxels. It is possible to think of the beam's absorption as being the total of all the voxels it has passed through as it moves across the volume. For contemporary scanners, this might be up to 512 voxels.

The movement of X-ray beams coming from various angles, traveling through, and being absorbed by a section of the body is usually picked up by the detectors [12].

**Magnetic Resonance Imaging**

MRI is a cross-sectional imaging technique that is non-invasive and doesn't use ionizing radiation [13]. The basic concept of magnetic resonance, which Felix Bloch and Edward Purcell first defined in 1946 and for which they were awarded the Nobel Prize in Physics in 1952, is used by MRI to acquire images [14]. A Nobel Prize in Medicine was awarded to Paul Lauterbur and Peter Mansfield in 2003 for their explanation the process of obtaining MR images from the human body [15, 16]. Since that time, the field of MRI has developed significantly, and it is today a recognized and sophisticated imaging technique in radiology that enables the acquisition of time- and high-resolution anatomical pictures [17].

**MR Imaging Principle**

For clinical MRI scanners, strong superconducting magnets are needed for the common therapeutic procedures of field strengths 1.5 Tesla and 3 Tesla [13], where a patient will be moved inside the bore of the magnet with a powerful static magnetic field $B_0$ that ranges from 0.2 Tesla to 3 Tesla as illustrated in figure 3.

The water molecules that make up the human body each have two protons, which are hydrogen atoms. These protons' magnetic moments line up with the static magnetic field's direction inside the scanner. The patient's body is then imaged using gradient fields and oscillating electromagnetic radiofrequency fields. An RF coil creates the radiofrequency field B1, and three separate coil systems (Gx, Gy, and Gz) placed in the MRI scanner's bore create the fast-switching gradient fields [18].

**Fig 3:** A front-facing patient table, capable of being repositioned within the magnet's bore, is a feature of the clinical MRI system.

**Positron Emission Tomography (PET)**

The functional processes in the body are visualized by using the medical imaging technology known as positron emission tomography (PET), which employs a small quantity of radioactive material known as a radiotracer. The radiotracer emits positrons, which are positively charged particles that interact with electrons in the body to produce gamma rays. These gamma rays are detected by a PET scanner, which creates three-dimensional images of the distribution and concentration of the radiotracer in different organs and tissues. PET can provide information about the metabolic activity, blood flow, oxygen consumption, and receptor binding of tissues, and is used in the diagnosis, staging, and monitoring of a various diseases, such as cancer, neurological disorders, and cardiovascular disease. In gamma camera imaging, photons are emitted and detected one by one. To accurately determine the location of these events, a collimator is required, but the capability of collimator is confined to a portion of the photons to reach the camera's surface, resulting in a considerable reduction in the efficiency of gamma camera detection.

When a positron emitter decays radioactively, it emits pairs of 511 keV gamma rays (positron-emitting radionuclide) that are detected using PET (positron emission tomography). The positron and electron then interact, leading to positron-electron annihilation. A pair of 511 keV, 180, and simultaneous gamma rays are produced by this annihilation [19, 20]. These three characteristics of gamma rays allow for their imaging using coincidence detection rather than collimation.

Two 511 keV gamma rays are identified in the coincidence detection with a pair of detectors facing opposite directions (180°). Only when the two photons are simultaneously detected by the detector at 180° and within the 511 keV energy windows (e.g., 30% peaked at 511 keV) can the PET record a positron-electron annihilation event. The term "same time" in this context actually refers to a timing window of around 10 ns. When compared to single photon imaging, this detection is analogous to electronics collimation because a gamma emission event can only be detected when photons fall within a certain energy window (for example, 20% centered at 140 keV for Tc-99 m) and pass through collimator holes.

Multiple rings of tens of thousands of scintillation detectors are used in a modern PET camera. For coincidence detection, the ring structure offers a large number of paired detectors.

To increase the effectiveness of the PET imaging, the many rings cover a "section" rather than a "slice" of the imaging subject. Typically, five to seven sections are needed to complete a whole-body scan.

To ensure effective photon reflection with an energy of 511 keV, PET scanners require scintillation crystals. Both NaI (Tl) and BGO (bismuth germanate) are scintillation materials commonly used in radiation detection and measurement applications. BGO and NaI(Tl) both have their own advantages and disadvantages, and which one is preferable will depend on the specific requirements of the application. However, there are some scenarios where BGO may be preferable over NaI(Tl):

1. **High-energy gamma ray detection:** BGO has a higher density and atomic number than NaI(Tl), which makes it more efficient at detecting higher energy gamma rays and X-rays. This can make BGO preferable for applications that involve detecting radiation in the high-energy range.
2. **Low background radiation:** BGO has a relatively lower background radiation signal compared to NaI(Tl), which can make it a better choice for applications where low background noise is important, such as in high-energy physics research.
3. **Stability:** BGO is less hygroscopic than NaI(Tl), meaning it is less susceptible to moisture and humidity. This can make BGO more stable and less prone to degradation over time.
4. **Spatial resolution:** BGO crystals have a higher density than NaI(Tl) crystals, which can result in better spatial resolution in certain imaging applications.
5. **Cost:** While the cost of BGO and NaI(Tl) crystals can vary depending on the size and quality, in some cases BGO may be more cost-effective than NaI(Tl).

BGO was once the standard PET crystal until LSO was introduced, which accelerated scintillation or reduced crystal deterioration.

With its high scintillation efficiency, superior stopping power, good energy resolution, and absence of hygroscopes, BGO proves to be an extremely effective scintillation material for PET imaging. The LSO crystal, which is a scintillator crystal of the latest generation, features excellent properties such as exceptional energy resolution, quick decay time, high light output and density, and low cost. As a result, LSO is a fantastic option for a wide range of PET imaging gamma ray detection applications. Figure 4 illustrates that numerous manufacturers of PET scanners utilize crystals that are comparable to LSO, including GSO (gadolinium oxyorthosilicate) and LYSO (cerium-doped lutetium yttrium orthosilicate).

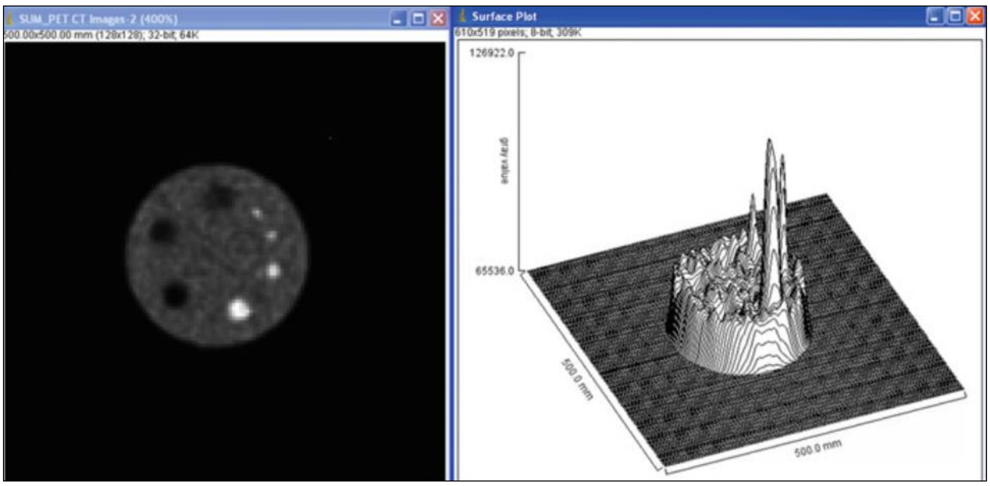


**Fig 4:** PET image of F-18 in an ACR phantom. White holes are hot spheres, black holes are cold spheres, and the gray area in the cylindrical container represents background activity. The image on the right shows how the activity is distributed among the several spheres [21].

**Multimodality Imaging**

Multimodality imaging refers to the use of multiple imaging modalities, such as positron emission tomography (PET), computed tomography (CT), magnetic resonance imaging (MRI), or ultrasound, to obtain a more comprehensive and accurate picture of a patient's condition. By combining the strengths of different imaging techniques, multimodality imaging can provide information about the structure, function, metabolism, and molecular characteristics of tissues and organs. This approach is particularly useful in the diagnosis, staging, and treatment planning of cancer and other complex diseases

CT scan is a non-invasive diagnostic imaging technique that uses X-rays to produce detailed cross-sectional images of the body. A CT scanner rotates around the patient and takes multiple X-ray images from different angles. These images are processed by a computer to create detailed 3D images of the body's internal anatomy, including bones, soft tissues, and organs. CT scans are particularly useful in diagnosing injuries, fractures, and tumors.

PET scan, on the other hand, is a type of nuclear imaging that uses a small amount of radioactive material (called a radiotracer) to produce detailed images of the body's internal organs and tissues. The radiotracer is injected into the patient's bloodstream, where it travels to the target organ or tissue. As the radiotracer decays, it emits positrons, which collide with electrons in the body and produce gamma rays. These gamma rays are detected by a special camera, which creates detailed 3D images of the organ or tissue being studied. PET scans are particularly useful in diagnosing and monitoring various types of cancer, as well as detecting abnormalities in the brain. By combining two dependable imaging techniques into a single scan, the PET-CT scan provides several advantages. The CT component of the PET-CT scanner furnishes a body attenuation map and an anatomical characterization of internal organs to enable attenuation correction. Recently, an imaging facility using PET-MRI has been established to exploit the benefits of both established imaging methods.

A SPECT/CT is a hybrid imaging technique that combines the strengths of both SPECT and CT scans. It involves taking a SPECT scan and a CT scan at the same time, using the same machine. The resulting images provide information about both the function and structure of the organ or tissue being studied, which can provide more detailed and accurate information than either technique alone.

Before they are combined into a single imaging unit, PET and CT or PET and MRI imaging modalities are independently accessible, and thus, most multimodality imaging systems use image registration algorithms to merge images from several modalities and produce a fussed image. In the case of a PET-CT scan, for example, the fussed image retains the functional distribution of radioactive isotopes within the organ structure that is anatomically defined.

As the two modalities are calibrated at the factory by the manufacturer, calibration factors do not need to be created by users to register two sets of images. However, if two sets of images are obtained from separate imaging units using different modalities, software fusion is required, and calibration factors can be generated using landmark points.

## Conclusion

The image acquisition techniques discussed in this study can be divided into projective and non-projective approaches, physiological and functional imaging techniques, and methods for measuring physical effects. Each method generates data that is known to be connected to physiological and/or functional characteristics. It can be assumed that the choice of an imaging technique is always deliberate in order to take advantage of this relationship for further investigation.

As artefacts are frequently technique-specific, this information may and should be utilised when creating an analysis method.

The phrase "medical picture" encompasses a wide range of various signal types to be captured as well as various acquisition methods. Therefore, every time a new analysis task must be completed with the aid of an algorithm that operates automatically or semi-automatically, understanding the semantics of the image will demand a fresh effort. One of the main distinctions between processing medical photos and ordinary images is this. Another crucial point is that the portrayal typically consists of a projection of transparent materials rather than mostly opaque ones, as in scintigraphy or x-ray imaging, or a comprehensive recreation of a 3D (or perhaps 4D) scene. Since many computer vision algorithms are focused on recovering distances or treating partially hidden structures, these issues are not the main focus of analysis of medical images. Dealing with insufficient distinction of structures of interest, image capture artifacts, and the inaccessibility of the data to be examined are the key challenges in medical image analysis.

## References


1. Butler EB, Teh BS, 3rd Grant WH, *et al*. SMART (simultaneous modulated accelerated radiation therapy) boost: a new accelerated fractionation schedule for the treatment of head and neck cancer with intensity modulated radiotherapy. Int. J Radiat Oncol Biol Phys. 1999;45:21-32.
2. Manning MA, Wu Q, Cardinale RM, *et al*. The effect of setup uncertainty on normal tissue sparing with IMRT for head-and-neck cancer. Int J Radiat Oncol Biol Phys. 2001;51:1400-1409.
3. Zelefsky MJ, Fuks Z, Happersett L, Lee HJ, *et al*. Clinical experience with intensity modulated radiation therapy (IMRT) in prostate cancer. Radiother Oncol. 2000 Jun;55:241-249.
4. De Meerleer GO, Vakaet LA, De Gersem WR, De Wagter C, De Naeyer B, De Neve W. Radiotherapy of prostate cancer with or without intensity modulated beams: a planning comparison. Int. J Radiat Oncol Biol Phys. 2000;47:639-648.
5. Qi XS, Hu A, Lee SP, Lee P, DeMarco J, Li XA, *et al*., Assessment of interfraction patient setup for head-and-neck cancer intensity modulated radiation therapy using multiple computed tomography-based image guidance. Int J Radiat Oncol Biol Phys. 2013a;86(3):432-439.
6. Jaffray DA, Bissonnette JP, Craig T. X-ray imaging for verification and localization in radiation therapy in modern technology of radiation oncology (suppl. 1). Modern technology of radiation oncology. Medical Physics Pub, Madison, WI. Isbn. 1999, 0–944838–38-3.
7. Siegel R, Ma J, Zou Z, Jemal A. Cancer statistics,. CA Cancer J Clin. 2014;64(1):9-29.
8. Tabar L, Yen MF, Vitak B, Chen HH, Smith RA, Duffy SW. Mammography service screening and mortality in breast cancer patients: 20-year follow-up before and after introduction of screening. Lancet. 2003;361(9367):1405-1410.
9. Tabar L, Vitak B, Chen TH, Yen AM, Cohen A, Tot T, *et al*. Swedish two-county trial: impact of mammographic screening on breast cancer mortality during 3 decades. Australas Radiol. 2011;260(3):658-663.
10. Nystr€om L, Andersson I, Bjurstam N, Frisell J, Nordenskj€old B, Rutqvist LE. Long-term effects of mammography screening: updated overview of the Swedish randomised trials. Lancet. 2002;359(9310):909-919.
11. Popli MB. Pictorial essay: mammographic features of breast cancer. Indian J Radiol Imaging. 2001;11:175-179.
12. Muhammed Maqbool. An Introduction to Medical Physics, the University of Alabama at Birmingham,

Birmingham, AL, USA, Springer International Publishing AG; c2017.
13. Sammet S, Koch RM, Aguila F, Knopp MV. Residual magnetism in an MRI suite after field-rampdown: what are the issues and experiences? J Magn Reson Imaging. 2010;31(5):1272-1276.
14. Nature Nobel prize for physics, Nature. 1952;170(4335):911-912.
15. Lauterbur PC. Image formation by induced local interactions. Examples employing nuclear magnetic resonance. Clin Orthop Relat Res. 1973;1989(244):3-6.
16. Lauterbur PC. Nobel lecture. All science is interdisciplinary–from magnetic moments to molecules to men. Biosci Rep. 2004;24(3):165-178.
17. Roldan-Valadez E, Lopez-Mejia M. Current concepts on magnetic resonance imaging (MRI) perfusion-diffusion assessment in acute ischaemic stroke: a review & an update for the clinicians. Indian J Med Re. 2014;140(6):717-728.
18. Kanal E, Shellock FG, Talagala L. Safety considerations in MR imaging. Radiology. 1990;76(3):593-606.
19. Bushberg JT, Anthony Seibert J, Leidholdt EM. Jr, Boone JM. Essential physics of medical imaging, 3rd edn; c2011. ISBN-13: 978-0781780575.
20. Sorenson JA, Phelp ME. Physics in nuclear medicine, 2nd ed., Grune and Stratton, New York; c1987.
21. Nuclear Medicine Service, Virginia Commonwealth University Hospital System, Richmond, Virginia.