第 48 卷第 9 期
2021 年 9 月
湖南大学学报（自然科学版）
Journal of Hunan University（Natural Sciences）
Vol. 48. No. 9.
September 2021

Open Access Article

# PHYSICS BEHIND PET SCAN-A REVIEW

**Ritu Pasrija**
Physics department, DAV College, Abohar, Punjab

**Abstract:** There has been a great interest in the field of nuclear medicine and PET scan technology is an emerging field which has proved to be promising tool in the diagnosis and treatment of various diseases like cancer etc. The underlying physics behind PET scan is quite interesting. This paper provides a review of an insight into the mechanism involved in the process along with its potential applications.
**Keywords:** Positron Emission Tomography, gamma camera.
**摘要**：**核医学**领域引起了极大的兴趣，PET 扫描技术是一个新兴领域，已被证明是诊断和治疗癌症等各种疾病的有前途的工具。 PET 扫描背后的基础物理学非常有趣．**本文**综述了对该过程所涉及的机制及其潜在应用的深入了解。
**关**键词：正电子发射断层扫描，伽马相机。

## Introduction

PET (Positron emission tomography) scan has been at the core of nuclear medicine and has set new horizons as far as the diagnosis of many diseases is concerned at the very early stages and it is better than the conventional single photon imaging i.e. SPECT. It can detect early signs of cancer, heart disease, and brain disorder [1]. This scan produces images of the body organs and tissues at work. A safe chemical is injected into the body of patient which absorbs the chemical and moves around the body along with the blood. This is used to study or image the behavior of organs and tissues in terms of energy emitted by the chemical. A PET scanner is a large machine having a round shape/ donut- shaped hole in the middle. It has many rings of detectors to record the energy given out by the injected chemical from the body. The patient is made to lie on a table that slides between two parallel gamma cameras on either side of the patient. The data from the gamma camera is fed into a computer to produce an image. This process causes no pain or a little discomfort to the patient.

The special dye which contains radioactive tracers is injected into the body (swallowed, inhaled or injected into vein) depending on the organ under study. The infected areas are rich in chemical activity react more with this radiotracer as compared to the normal chemical activity. This shows up in the scan as bright spots.

A PET scan can inspect the blood flow, intake of oxygen or metabolism of the organs. It can detect over a longer period of time, the radiation coming from patient's body. It has been used for the following purposes [2]

1. For detecting cancer
2. To check the effectiveness of the ongoing treatment.
3. Evaluate prognosis.
4. Determine the effects of heart attack.
5. Check for the brain abnormalities/tumors etc.
6. Alzheimer's disease and Dementia.

## 1. A PET scan is different from CT scan or MRI scan

CT scan is computed tomography which uses X-rays and MRI scan is magnetic resonance imaging which uses magnets and radio waves. All these produce images of different organs of the body. They can give idea about the size and

Received: July 02, 2021 / Revised: August 22, 2021 / Accepted: September 11, 2021 / Published: September 25, 2021
About the authors: Ritu Pasrija

Corresponding author- Email: Ritu Pasrija

shape of body organs or tissues, but PET scan shows how the organs work.
PET also differs from other examinations in nuclear medicine. These measure the metabolism within the body tissue whereas the other nuclear medicine examinations detect the amount of substance collected in the tissue.
The knowledge of the photon direction gives an advantage over single photon emission tomography (SPECT). In SPECT the direction of photons is guided by the use of collimators which reduces its sensitivity.

## 2. The mechanism behind PET Scan

The main component behind the PET scan is the radionuclide which is unstable and it changes their properties by emitting a smaller particle to come to a lower energy or stable state. This phenomenon is called radioactivity. Radioactivity follows an exponential law. The decay law depends on the half life of radionuclide.

$$dN / dt = N_0 e^{-\lambda t} \quad (1)$$

Where λ is the disintegration constant and is 0.893 times the inverse of half life, τ of the radionuclide. N is the number of atoms at any time, t and N0 is the number of atoms present originally in the sample. The radioactivity is measured in millicurie or Becquerel. For PET scan some of the radionuclides used are F-18, N-13, O-15, C-11 etc. Some of these isotopes can be incorporated into biological substrates like glucose, CO2 etc. and other pharmaceuticals without changing their biological activity.
The radioactive tracer used in the process is determined by the part of body under study. For example, in case PET scan of brain is to be done, the radioactive atom is attached to glucose which gives a radionuclide called 2-[18F]-fluoro-2-deoxy-D-glucose (FDG). FDG is used by the brain for its metabolic activity [3].
When a nucleus decays a proton is converted into a neutron along with the emission of positron. The positron then takes up a free electron within the body and releases energy in the form of photons. The PET scan detects two photons emitted in positron- electron annihilation. The positron in emitted by the radiotracer which is injected into the body. The radionuclide such as F18 or C-11 emit the positron undergoes annihilation with the electrons, two photons are produced back to back which can be detected outside the body by the gamma ray spectrometers of the PET scan machine. The process can be visualized as shown in the figure 1.

## 3. Gamma cameras

Gamma cameras used in PET scan consist of scintillation detectors containing sodium iodide crystal, relatively thinner than compared to

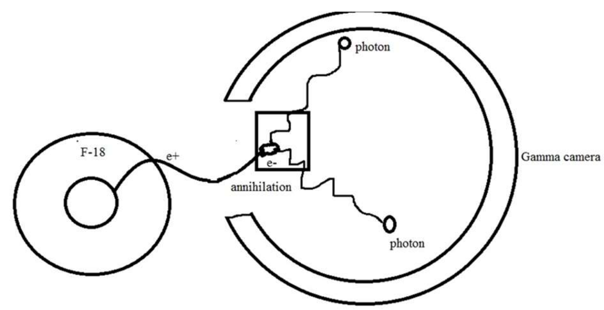


Figure 1. Schematic diagram of mechanism involved in a PET scan.

This leads to the production of F-18 radioisotope.

$$H_2O(enriched) + H^- + energy \rightarrow H_2F(contains F18)$$

(2)

F-18 is an unstable nucleus and has a short half life of 109 minutes. It decays to O-18 giving us a beta particle (positron) and a photon.

$$_9F^{18} \rightarrow {}_8O^{18} + {}_{+1}e + \gamma \quad (3)$$

This positron then annihilates with the electron to give two coincident photons.

$$_{+1}e + {}_{-1}e \rightarrow \gamma + \gamma \quad (4)$$

The gamma photons are collected by gamma ray spectrometers which helps us to do energy analysis of the patient's body.
gamma detectors for other applications. It is nearly 100 percent efficient for energies up to about 100keV. These consist of sodium iodide crystal in combination with photomultiplier tubes and pulse width analyzers and amplifiers. The photons enter into the camera after they are

formed by electron-positron annihilation process within the body. These photons are guided to photomultiplier tubes using collimators where they are converted into electrical signals which are then digitalized using analog to digital convertors and then fed to pulse height analyzers to perform the energy analysis resulting into an image. The use of pulse height analyzers allows the user to select the energy range according as the need be [4].

## 4. Data acquisition

The important job is to measure the total energy deposited by the collected photons. It depends on the efficiency of the detector to collect the photons. Different types of detectors have different efficiencies. The incident photons are collected by the scintillation material which produces more photons of different energy ranges (UV or visible range). These then interact with photocathode to emit electrons in a photomultiplier tube which produces an electrical signal. The number of photons produced in the scintillator is directly proportional to the energy deposited by the annihilation photon. The data is acquired in terms of sinograms.

The properties which decide the efficiency of scintillator to be used in PET scan are the stopping power, the decay constant, energy resolution and the light output. A good energy resolution helps the detector to distinguish between the Compton scattered photons that have lost energy before they are measured. Shorter decay constant ensures higher counting rates. Dead time of the scanner is also determined by the decay constant. Light output determines number of photons produced by the incident photon. Various scintillators used in PET imaging are Sodium iodide (thallium doped), bismuth germinate (BGO), lutetium yttrium orthosilicate (LYSO) etc. The scintillator blocks and the PMT, together determines the location of photon detection.

The data acquisition can vary from patient to patient as interaction of photons in the patient may vary or it depends upon the part of body under study. The efficiency of different detector elements can be different. Random coincides can be recorded along with the desired coincidences. All these parameters need to be adjusted to obtain images which are clinically useful.

## 5. Image reconstruction

After the data is obtained and correction due to attenuation is applied, we need to reconstruct the image which the doctor requires to analyze. Two most common methods used for this process are filtered backprojection (FBP) and ordered subsets expectation maximization (OSEM). The OSEM method accounts for error due to noise using iteration methods and is the commonly used nowadays.

## 6. Future aspects of PET scan

PET has become a growing imaging modality. Its instrumentation has evolved with improved versions of hardware and software used with digital photomultipliers and involved electronics. These offer a greater potential in many imaging diagnostic procedures in surgical planning and cancer staging. Simultaneous PET/CTs and PET/MRIs have been developed and are being used for diagnosing tumors of almost every part of the body including brain, spinal cord, liver, heart etc [5]. Brain PET scan allows the doctor to detect brain cancer, tumors, diagnose dementias, Alzheimer's disease and differentiate between the Parkinson's disease condition and other condition. When radiotracers have been absorbed in the blood stream by attaching them to glucose, the scan is performed and active areas and inactive areas are decided and anomalies are determined on the basis of amount of glucose absorbed by the part of brain. Heart PET scan allows the detection of arrhythmia, pain in chest, breathing trouble, profuse sweating. The details of areas of decreased blood flow can be determined. Generally this test is combined with a vasodilator. The doctor finds out how much damage has been caused to the heart and how the patient is responding for the ongoing treatment [6]. PET with Flurorine-18 (F-18) as a tracer is being used to carry out scans of bones for diagnosis of lower back pain disorders. It provides accurate anatomical details. It plays an important role to identify causes of persistent back pain following vertebral surgical interventions [7]. PET based on 18F-FDG can access tumor malignancy, treatment response better than conventional imaging methods [8]. Efforts have been made to compensate PET scan for cardiac patient motion thereby improving the quality of image. New data acquisition techniques also include bed motion [9].

## 7. Concerns behind the PET scan

PET is an invasive and expensive method. Along with PET apparatus, a cyclotron and a special laboratory is required for installation as the radioactive tracers are short-lived. Also, a mechanism for storage of radioactive tracers or its transportation is a tedious task. This involves a huge investment and maintenance charges which makes it out of reach for poor sections of the society. Small quantities of doses are administered which yield a poor quality image. Nevertheless, at present this seems to be the only method available for some scientific tasks.

## 8. Conclusion

PET scan is a type of procedure in nuclear medicine. It combines nuclear activity of the radioactive element used with the biochemical analysis. It is more close to the study of the metabolic activity of different cells of body tissues. PET is most often used by oncologists, neurologists and neurosurgeons and cardiologists to detect and manage the treatment of many severe diseases. Moreover the radiotracers are relatively short-lived. This enables optimal use of imaging photons along with keeping patient radiation dose low. A major advantage of PET imaging is the fact that due to the positron annihilation we can observe two photons at the same time (in coincidence) approximately in the detector ring. The annihilation event, i.e. the radioactive tracer, is located somewhere on the line joining the two photon-detection points.

This procedure is being widely used in many areas making this area more prone to advances in the technology. The future of these scans in combination with MRI and CT are very healthy and heartening.

## References

1. D. L. Bailey, D. W. Townsend, P. E. Valk and M. N. Maisey, Positron Emission Tomography, Springer, 2005.
2. V. Rangarajan, N. C. Purandare, A. R. Sharma and S. Shah, PET/CT: Current status in India, Indian J. Radiol Imaging, 2008, 18(4): 290-294.
3. Newberg A., Alavi A. and Reivich M., Determination of regional cerebral function with FDG-PET imaging in neuropsychiatric disorders". Seminars in Nuclear Medicine., 2002, 32 (1): 13–34.
4. Y. D. Asseler and S. Vandenberghe, et.al, PET imaging using gamma cameras, Computerized Medical Imaging and Graphics, 2001, 25: 87-96.
5. Mathematics and Physics of Emerging Biomedical Imaging, Washington DC: The National Academies Press, 1996.
6. https://my.clevelandclinic.org/health/diagnostics/17376-cardiac-positron-emission-tomography-pet
7. S. Gamie and T. El-Maghraby, The role of PET/CT in evaluation of Facet and Disc abnormalities in patients with low back pain using (18)F-Fluoride, Nucl. Med. Rev.cent east eur., 2008, 11(1): 17-21.
8. W. H. Martin, D. Delbeke, J. A. Patton and M. P. Sandler, detection of malignancies with versus PET, SPECT with 2-[fluorine-18]fluoro-2-deoxy-D-glucose, Radiology, 1996, 198(1): 225-31.
9. P. J. Slomka, T. Pan and G. Germano, Recent Advances and future progress in PET instrumentation, Seminars in Nuclear Medicine, 2016, 46(1): 5-19.