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# Development and Application of Gamma Camera in the Field of Nuclear Medicine

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**Abstract:** The gamma camera provides fast and accurate real-time imaging of the distribution of radionuclides in the human body. It can not only perform dynamic and static observations, but also can be used to observe the metabolism of local tissue organs. It is an important tool in the field of nuclear medicine. This paper introduces the principle, structure and performance index of gamma camera, and summarizes and analyzes the application and development status of gamma camera in nuclear medicine. The performance indicators of gamma cameras have been greatly improved, and have been widely used in the medical field.

**Keywords:** Gamma Camera, Nuclear Medicine, Imaging Technology

## 1. Introduction

Gamma ray imaging technology is a nuclear radiation detection technology for radioactive substances. Gamma camera is a device that can detect the radiation produced by radionuclide in human body. It has the advantages of fast imaging and high positioning accuracy. In 1958, HalO. Anger used the parallel hole collimator, NaI (Tl) crystal and the photomultiplier array, and designed the famous Anger camera by the center of gravity method. It can fast dynamic imaging, output two-dimensional flat film, and then combine multiple gamma cameras to get three-dimensional images. Most of the commercial gamma cameras are large detectors at present. In addition to being a separate mobile imaging system, small gamma cameras can also be combined with other specialized imaging systems. Single photon emission computed tomography (SPECT) and positron emission tomography (PET) are also developed on the basis of gamma camera [1].The main function of a gamma camera with SPECT system is to scan the brain, heart, breath, liver and kidney. The SPECT system is more sensitive than the ordinary gamma camera, but the cost of purchase and maintenance is relatively high[1].Therefore, small volume portable gamma cameras will have high research value in the future.

## 2. Principle and structure of gamma camera imaging

Gamma rays or X rays produced by radiation sources are scintillated through thick pinholes. The interaction between radiation and scintillator transforms the intensity image into a fluorescence photon, shown in Figure1. It is amplified by photomultiplier tubes and converted into measurable electrical signals. We can get the position and energy signal of the scintillation point through position circuit and energy circuit. Then the optical fiber is output to the computer for subsequent processing.

The basic components of gamma camera include collimator, scintillator, photomultiplier tube (PMT) and position logic circuit. At present, the structure of the common gamma imaging system can be divided into the following kinds: (1) collimator + monolithic scintillator + position sensitive photomultiplier tube (available PMT array, PD array, APD array replacement) + readout circuit. It has the advantages of simple structure, position and energy resolution. However, the monitoring area is small and the spatial resolution is low.

(2) collimator + array detector + readout circuit; The imaging structure adopts array detector mode with high spatial resolution and large pixel array. But the structure is complex and high cost. It is difficult for some detectors to be machined.

(3) collimator + scintillator + image intensifier + CCD; The structure of the imaging structure is based on the CCD. It can be coupled with a whole scintillator, array scintillator, and flat panel detectors. In this system,the mirror and the lens are needed. It has high spatial resolution and readout circuit is easy to implement. The biggest disadvantage is that CCD has no energy resolution, and the system can not carry out energy resolution [2]。


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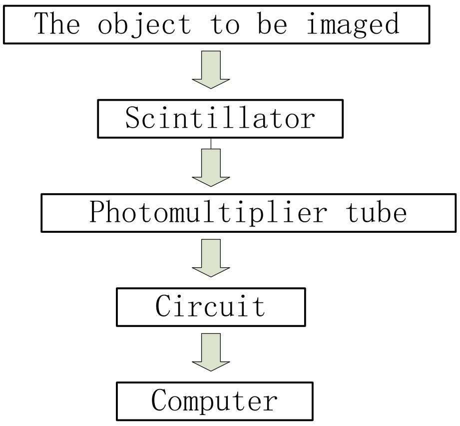


Figure.1 Basic structure of the gamma camera

## 3. Performance of gamma camera

### 3.1 Intrinsic resolution

The intrinsic resolution is the minimum distance that the imaging system can resolve the two point source images, which is reflected in the sharpness and detail of the image produced by the gamma camera. The spatial resolution of gamma camera consists of three parts: the inherent resolution of the probe, collimator resolution and scattering resolution. The spatial resolution of the gamma camera system depends primarily on the resolution of the collimator. At present, collimators are divided into four types: parallel porous collimators, pinhole collimators, convergent collimators and divergent collimators. Most gamma cameras use a parallel porous type. The more holes, the higher the resolution, but the spacer between the holes and the holes absorbs the photons of all the laterally truncated spacers, thus reducing the sensitivity of the system. Good spatial resolution of gamma camera up to 5~7mm. In practical applications, the closer the distance between the patient and the gamma camera, the better the spatial resolution [3]。A tradeoff in sensitivity is inherent in the use of a collimator, and modern preclinical single photon emission computed tomography (SPECT) systems detect a very small fraction of emitted gamma rays, often less than 0.1%. A system for small animal SPECT imaging which uses no collimators could potentially achieve very high sensitivity-several tens of percent-with reasonably sized detectors. [4]。Haining [5] developed a small gamma camera based on position sensitive photomultiplier. The spatial resolution of the 241Am source for the collimator of the 2mm diameter was ~4mm, and the resolution of the plane 57Co source was 27%. GK Loudos[5] studied a small gamma camera based on position sensitive photomultiplier for small animal imaging with a resolution of 2~3mm.

### 3.2 detection efficiency

Detection efficiency refers to the ratio of the number of radioactive source samples observed by gamma camera to the decay rate of radioactive source samples. The detection efficiency is related to ray type, energy, linear attenuation coefficient, detector thickness and window width set by PHA. Increasing the thickness of the crystal can increase the detection efficiency but reduce the intrinsic resolution.

### 3.3 sensitivity

Sensitivity is the counting rate of each activity detected. The overall sensitivity consists of geometric sensitivity and inherent sensitivity. The geometric sensitivity is the fraction of the emitted radiation that is intersected or impacted by the detector, i.e. the fraction of the total solid angle corresponding to the detector. Therefore, it is directly proportional to the area of the radiation sensitive detector, which is inversely proportional to the square of the source detector distance. The intrinsic sensitivity is a part of the radiation of the impact detector, which stops in the detector. Because the higher energy photon is more penetrable and more likely to pass through the detector without interaction, the intrinsic sensitivity is directly related to the thickness of the detector, the effective atomic number and mass density, and decreases with the increase of photon energy. The characteristic X rays and gamma rays are emitted by radioactive decay atoms with well-defined discrete energy.

### 3.4 Energy resolution

Energy resolution refers to the ability of a nuclear radiation detector to distinguish the Y peak of a similar energy, which is usually expressed by the half height width (FWHM) of the photoelectric peak. Energy resolution is related to photon energy and detector size. The higher the photon energy, the better the energy resolution.

### 3.5 Image nonlinearity

Image nonlinearity is the basic problem that occurs when a linear object is displayed as a curve image; if the imaging line is inwardly curved, it is called "occipital distortion" and if the imaging line is curved outward; it is called "barrel distortion". The reason for the nonlinearity is that the X and Y position signals do not linearly change with the displacement distance of the radiation source through the detector surface, and the sensitivity difference in the PM tube and the nonuniformity of the optical conductivity. Zhao Shujun [6] developed a real-time correction software for the space nonlinear distortion of the gamma camera.

### 3.6 Image nonuniformity

Image nonuniformity is that when the crystal detector is exposed to a uniform radiation flux, it will produce an extensive field image with small apparent intensity nonuniformity. The reasons for the nonuniformity of the image are the difference of the output signal height of different PMT, the relationship between the efficiency and the location of the glint collecting light and the nonlinearity of the image.

For camera design, the main goal is to develop systems with the best resolution and sensitivity. High sensitivity increases the signal to background ratio, reduces the time required for imaging process or reduces the radiation dose to patients. Good energy resolution and high spatial resolution provide more precise positioning and better quantitative accuracy..

**4.Application**

Scintillators in gamma cameras require better imaging performance ,such as high density, high atomic number, short decay time, high light output and low cost [7]。The commonly used scintillators are NaI (Tl), BGO, GCS, CsI (Tl), and gas detectors (such as high pressure xenon) and semiconductor detectors (such as CdTn, CdTe, GaAs, InP, HgI2, etc.) instead of scintillation [8]；Other new scintillator, such as avalanche photodiode (APD) and silicon drift detector (SDD), are also being studied. Portable gamma camera is also a new research direction. At present, in improving the size of gamma camera, it is possible to improve the scintillation in the gamma camera,in use of semiconductor detectors, such as Ge, CdTe or CdZnTe;coupled the scintillation crystal to the solid-state photodetector (photodiode) array; coupled the scintillation crystal to a position sensitive photomultiplier tube (PSMPT).

F Sánchez et.al[9] coupled CsI (Na) scintillation crystal to a new plate type multi anode position sensitive photomultiplier from Hamamatsu Photonics, and obtained a mini gamma camera.It is smaller in size and weight than traditional gamma camera, and there is no obvious loss in spatial resolution and sensitivity. The small gamma camera designed by J.M.Benlloch[10] is less than 2kg, the field of view FOV is 46mm, the spatial resolution is as high as 2mm, the 140 keV energy resolution is 12.8%, the plane sensitivity is 105 cpm/mCi. E Porras et.al [11] have developed a small portable, low-cost gamma camera for medical applications. It is based on a scintillation crystal and position sensitive photomultiplier, with a useful vision of 4.6 cm in diameter and an inherent spatial resolution of 2.2 millimeters; its mobility and light weight can reach the patient in any direction. The camera images small organs with high efficiency meets the needs of specific clinical applications.

Wangcheng [12] compared the gamma camera with SPECT thyroid dynamic imaging, and found that the sensitivity and accuracy of gamma camera for thyroid nodules larger than 1.0 cm in diameter were higher than SPECT. Ruan Yuyuan [13] used gamma camera to analyze the analysis of liver dynamic imaging and hepatic blood flow measurement in advanced cirrhosis. An ordinary gamma camera equipped with detection (CDET) can be used for the imaging of 2 types of renal cancer indications (characterization and staging of renal masses before nephrectomy and recurrence after nephrectomy)[14] and occult primary tumor in head and neck cancer[15].Ng A H [16] has studied the compact clinical application of small field of view hybrid gamma camera (HGC), which is suitable for small organ imaging of bedside patients. N. Giokaris et al[17] published a study on the optimization of the crystal and collimator of a high resolution gamma camera using a position sensitive photomultiplier.。Gregory Jerome Gruber[18] used compact gamma cameras for breast cancer or breast detection. Eric L.Brandly[19] et.al designed the mouse imaging with resolution and sensitivity based on the size of the mouse. Soluria et.al[20] developed a SSR method for molecular imaging and small animal imaging based on high resolution Gamma Camera, which significantly improved the spatial resolution. Young Sub Leea.b[21] et al use the pinhole collimator attached to the conventional gamma camera to monitor the animal models for imaging and treatment.

Hybrid imaging is a major innovation in nuclear medicine. Hybrid imaging is a major innovation in nuclear medicine. It uses a combination of PET-CT, PET-MRI and SPECT-CT to combine functional information with anatomical details. However, these scanners are relatively large and bulky. Gamma cameras are also widely used in ray measurements in astrophysics, high-energy physics, radiation environment monitoring, military and homeland security.

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