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Problem of Detection In Nuclear Medicine: From Anger To Czt, Clinical Applications In Nuclear Cardiology, Review Of The Literature.

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Abstract

In constant evolution since the 1960s, conventional gamma-cameras, based on the principle of indirect conversion developed by Hal Anger, have reached their limits in terms of detection sensitivity, counting rate, spatial resolution and energy resolution. Manufacturers were therefore prompted to propose other solutions in order to improve the performance of these imaging devices and, consequently, image quality. This is why, since 2008, a new generation of gamma cameras based on the use of semiconductor detectors has been introduced.

In 2010, semiconductors using cadmium-zinc telluride (CZT) revolutionized gamma cameras by allowing direct conversion of photons. These solid-state cameras, dedicated to cardiac scans, have an improved energy resolution (4 to 5% versus 10% for Anger cameras).

The objective of this study is to examine the characteristics of CZT detectors, paying particular attention to performance characteristics compared to the Anger camera in cardiological imaging.

1-Introduction

The field of nuclear medicine, one of the most sensitive methods for obtaining information on biological function for medical diagnostic purposes, predates the development of imaging radiation detectors by several decades(1)

The first studies used the radiotracer principle(2). In constant evolution since the 1960s, conventional gamma-cameras, based on the principle of indirect conversion developed by Hal

Anger, their continuous progress has led to an optimal compromise between detection sensitivity, spatial resolution, and energy resolution (3).

After many technological developments, manufacturers have therefore been led to propose other solutions in order to improve the performance of these imaging devices and consequently image quality. This is why, since 2008, a new generation of gamma cameras based on the use of semiconductor detectors has been introduced.

The objective of this study is to examine the characteristics of CZT detectors, paying particular attention to performance characteristics compared to the Anger camera in cardiological imaging.

2-Instrumentation

Comparative studies of conventional cameras with the CZT

As early as 1948, the Geiger-Müller counter made it possible to measure the photons NHRs emitted by the patient after administration of a radiotracer. In 1951, the scanning scintigraph made it possible to make the first scintigraphic acquisitions and it was replaced from 1958 by the gamma scintillation camera whose principle was developed by Hal Anger (3).

This camera allows to transform the energy of the incident photon knode into a measurable physical quantity (electric current) and locate the photons to make a scintigraphic image (radiotracer distribution). Anger's gamma camera consists of one or more detection heads, each with a collimator, an inorganic scintillating crystal (most often based on thallium-activated sodium iodide 201 (NaI(Tl)), a light guide, a set of photomultiplier tubes (PMTs) and associated electronics as shown in the figure below(4).

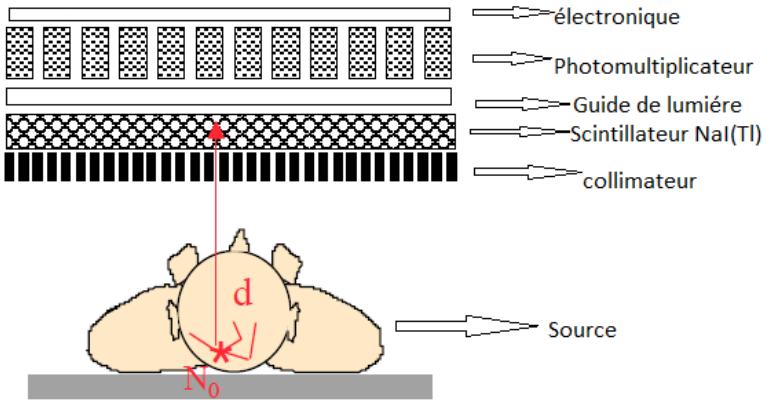

Figure 1: The composition of an Anger gamma camera detection head. (5)(Monophotonic emission tomography)

The cameras developed by Anger in the 1960s were optimized for many years to reach the limits of their performance in terms of detection sensitivity, counting rate, spatial resolution and energy resolution. Manufacturers have therefore chosen to focus on a new detection technology using semiconductors (SC).

Solid-state detectors offer several potential advantages over scintillators. The most important of these is that the direct conversion of the energy deposited by gamma-ray interactions into electron-hole pairs eliminates the optical-photon-signal electrical transducer step. In scintillators, this step invariably involves a loss of signal due to incomplete photon collection and possibly low quantum efficiency of the converters. By avoiding the need for cumbersome PMTs, solid-state imaging systems can also be made much more compact, reducing the amount of shielding and simplifying mechanics compared to the Anger camera. (6)

There are some drawbacks to PMT, including gain drift and potential photocathode fatigue (Marshall et al 1947). Furthermore, most PMTs to date have a relatively low quantum efficiency (25%), which means that most scintillation light does not generate an electrical signal(6).

In addition, the energy required to create an e–h (electron-hole) pair in most semiconductors used as radiation detectors is sufficiently low; that is, typical gamma-ray interactions generate a large number of charge carriers.

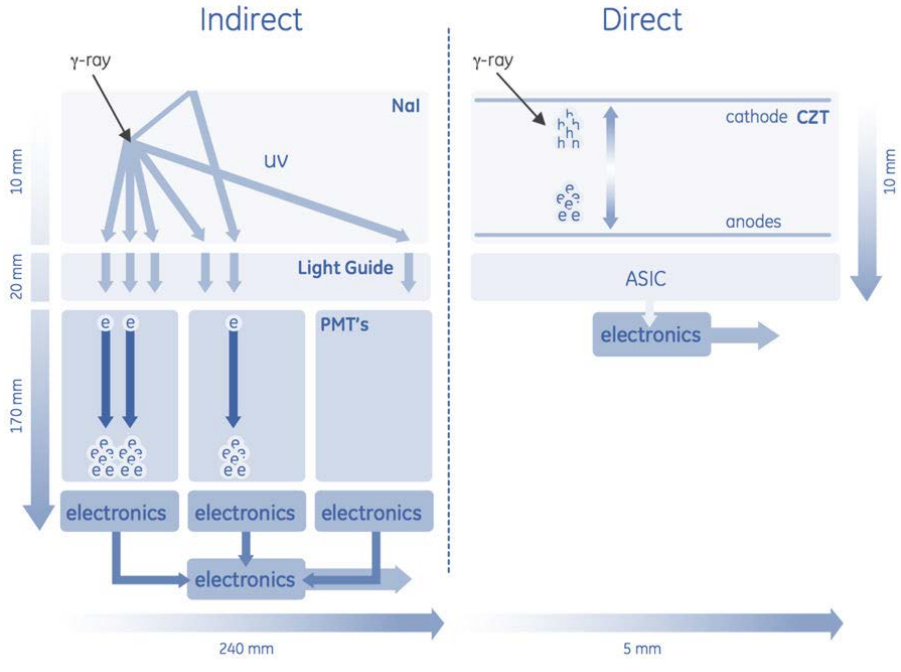

Figure 2: Principle of indirect conversion (NaI) on the left, and direct conversion (CZT) on the right(7).

❖ **Improved detection sensitivity**

As opposed to the indirect detection principle (conversion of a photon from O into light photons and then into an electrical signal), the interaction of a 140 keV energy photon from O in a CZT material produces about 30,000 electron-hole pairs (7) is 20 times more than with a sparkling crystal of NaI (Tl)(7).

❖ **Improved resolution in energy**

Since the signal can be directly used by the electronic circuits, the noise during measurement is reduced (low statistical fluctuations), so that the energy resolution is better. With the CZT semiconductor, it is improved by a factor of 2 compared to the NaI (Tl) detector for 140 keV energy NaI photons(8,9).

❖ **Improved spatial resolution**

The charges created at the site of the interaction are driven under the action of an electric field without loss of spatial information. The semiconductor material can therefore have a large thickness without degrading the spatial resolution.

Note that this is not the case for the scintillator used in the detection heads of Anger cameras, where the thickness is chosen according to the sensitivity/spatial resolution compromise (7).

3-Clinical applications

A clinical application that has recently motivated the development of new detection technologies is myocardial perfusion imaging. One of the reasons that clinical SPECT systems have long been a thematic review focused on the Anger camera is due to its ability to perform a wide range of imaging procedures, planar renal and bone scans to SPECT studies of cerebral blood flow, using a general-purpose system.

However, clinical nuclear medicine has evolved such that the majority of procedures are myocardial perfusion SPECT studies (stress rest tests) – cardiac studies accounted for 57% of all nuclear medicine procedures in the US in 2006 (10). The high demand for this type of study combined with the growing presence of scanners in cardiology offices has created a market for specialized SPECT systems.

This solid-state camera was evaluated in clinical routine at several centers (Table 1) and on a large number of patients with the technétiés tracers (11,12) and Thallium 201 (13) .

✓ Observation:

In a 135 kg patient for 1.60 m.

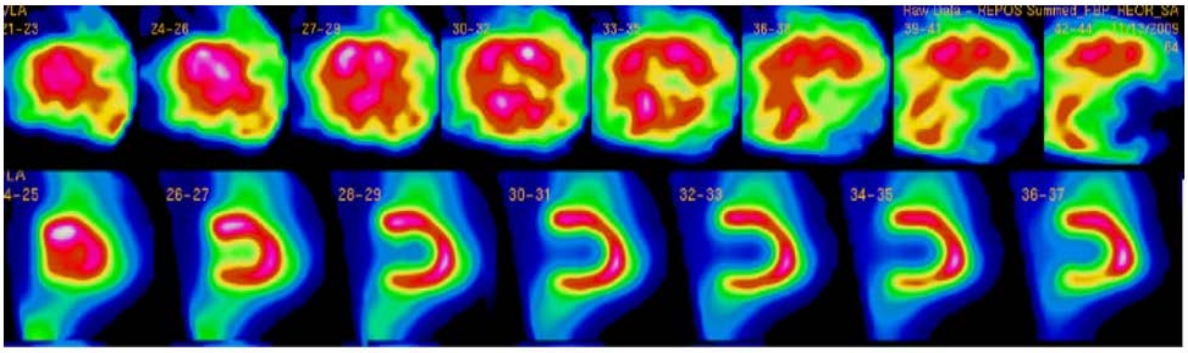

Figure 3: Sagittal slices obtained on the conventional camera (top) and on the D-Spect (bottom) in an obese patient.

Comment: There is a significant decrease in the acquisition time between images of 15 minutes for conventional camera and 5 minutes for D-Spect.

The acquisition performed on the conventional camera is not interpretable due to the partial volume effect.

D-Spect scans were found to be of better quality than conventional camera scans; they had fewer digestive artifacts, this quality gain being particularly evident in obese patients.(14)

4-Conclusion : In recent years, the main evolution in cardiac imaging has been brought by the commercialization of semiconductor cameras. We did this comparative evaluation to show the advantage of a czt detector in a hospital department that can influence the time of dosimetry acquisition and image quality to allow good patient management in collaboration with cardiologists.

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