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Single Photon Emission Computed Tomography as a diagnostic method in ischemic heart disease – basic technical aspects

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Summary

Ischemic Heart Disease (IHD) poses an important diagnostic problem. Clinical picture of the disease is often atypical. SPECT is one of the main diagnostic tools in ischemic heart disease. Radioisotope study evaluates distribution of a radiopharmaceutical agent in the heart through a series of scintigraphic images taken by an external gamma camera. This article discusses the technical aspects of cardiac SPECT imaging, starting with a detection system, through image reconstruction, and ending with image filtering.

Key words: SPECT • mTc-MIBI • myocardial perfusion

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Background

Nuclear medicine is one of the most important medical specialties. It utilizes radioactive isotopes for diagnostic and therapeutic purposes, providing necessary information about the anatomy of a given organ, its position and function [1,2]. Radioisotope diagnostics, due to its dynamic evolution and non-invasiveness became a recognized research method that provides a lot of prognostic data regarding cardiovascular events [3].

We owe the development of radioisotope imaging to a diagnostic method that involves detection of the activity of a radioisotope accumulated over a diagnosed organ along consecutive lines, and uses a single detector.

Single Photon Emission Computed Tomography (SPECT), available since 1960, is one of the basic tools in contemporary diagnostics of ischemic heart disease (IHD) [4]. For the first time, single-headed SPECT was used for research in mid 70s, to carry out a topographic reconstruction of an image with a filtered back projection (FBP) algorithm [5].

Radiopharmaceuticals

In single-photon tomography, radiopharmaceuticals emitting γ photons are used. Emitters of γ photons most

commonly used for diagnosing ischemic heart disease are ^{99m}Tc and ^{201}Tl isotopes, which accumulate in the myocardium [6] via active transport through cell membranes, proportionally to myocardial perfusion.

The Tl-201 isotope has been used in the diagnostics of myocardial perfusion since 1975, and ^{99m}Tc – MIBI complex since mid 80s [7,8]. The ^{99m}Tc is used for this kind of diagnostics due to its physical and biological properties, as well as cost and availability. The short half-life of ^{99m}Tc (Table 1) reduces patient's exposition to ionizing radiation connected with the application of diagnostic doses of radioactive technetium.

SPECT Detection System

The device used for γ photon detection in radioisotope diagnostics of ischemic heart disease is a rotating single- or double-headed gamma camera composed of a collimator, a crystal, photomultipliers, positioning system and other parts.

The detector, while rotating around the patient, detects γ photons that are perpendicular to the openings of the collimator [9]. There are different shapes and sizes of collimators, but most often used are parallel collimators that look like a honeycomb. Gamma photons, after passing through the collimator, are absorbed by a scintillation crystal

Table 1. A comparison of Tc^{99m} and ^{201}Tl isotopes.

	Technet-99m	Tal-201
Half-life $T_{1/2}$ [h]	6.02	73
γ photon energy [keV]	140 (98%)	167 (8%), 135 (2%)
Given activity of a substance [mCi]	10–30	2
Method of acquisition of the isotope	Generator	Cyclotron
Mother radionuclide	Molybdenum-99	Thallium-203

[10,11]. As γ photons fall onto the crystal, they react with it and are transformed into light photons. After an appropriate amplification (using secondary emission) and shaping, light photons are converted into a digital image. Collected images are processed by a computer (Figure 1).

Detector Rotation

The first investigations on the range of rotation of SPECT detector have been attempted in the 80s. There was a question of which rotation range (180° or 360°) is more beneficial to studying myocardial perfusion [12–14]. Due to a substantial improvement in image contrast and shortening of study time, image acquisition with a 180° rotation of the detector became a standard in this kind of myocardial diagnostics [15].

In case of a rotation of 180° , the study begins with a detector placed in LPO- 45° (left posterior oblique) and ends in RAO- 45° (right anterior oblique) position. This allows for obtaining a clearer spatial distribution of left ventricular regions than in the case of the rotation of 360° . During the investigation, 32 acquisitions are obtained with the 64×64 matrix [16], but study protocols with 128×128 matrix can also be used (Figure 2).

Topographic Image Reconstruction

Back-projection method

In single photon emission computer-aided tomography, reconstruction of the image with the back-projection method focuses on filtering of intended projections for a given acquisition angle. Images obtained with SPECT method represent the distribution of activity of an administered radiopharmaceutical in the diagnosed object.

In these kinds of reconstructions, mathematical equations are applied, such as the Radon transform (1) and Fourier transform (2) [17,18], which allow to obtain a two- or three-dimensional activity distribution on the basis of one-dimensional measurements:

$$g(s, \theta) = \int_{-\infty}^{+\infty} f(s \cos \theta - u \sin \theta, s \sin \theta + u \cos \theta) du \quad (1)$$

where:
 (s, θ) – detector coordinates (s – position, position angle);

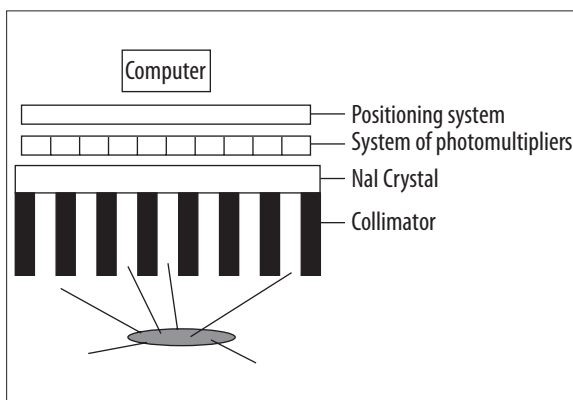


Figure 1. Construction scheme of scintillation gamma camera. Almost only gamma rays parallel to the openings in the collimator pass through the collimator.

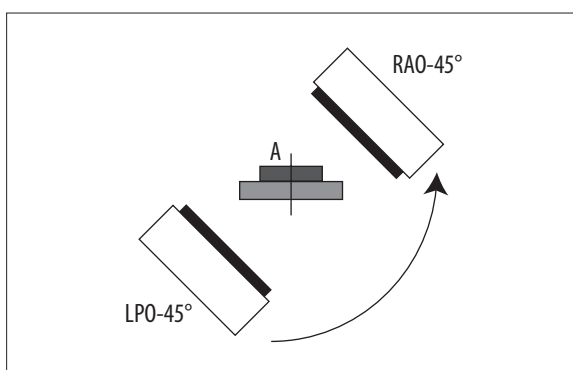


Figure 2. Positioning of SPECT detection system. A – patient positioned perpendicularly to this article, with his head from the outside.

u – variable describing the location of the summed points,

$$F(u) = e^{-\frac{(u-u_0)^2}{2\sigma^2}} ; u \geq 0 \quad (2)$$

During image reconstruction, in order to eliminate noise in acquired projections, filters are used to suppress i.a. high frequencies in places where signal is not detected and where noise dominates in measurements. An additional function of the applied filters is to smooth the acquired image in order to improve its quality and clarity (Figure 3).

Common use of filters results from the fact that they can be easily implemented, which is associated with intuitive expectations of a user of software applied in scintigraphic image processing.

Iterative methods

Iterative methods, next to the back-projection method, find application in SPECT image reconstruction. In single photon emission tomography, beside a filtered back-projection method, various algorithms such as MLEM (Maximum Likelihood Expectation Maximization) and MAPEM (Maximum A Posterior Expectation Maximization) are used

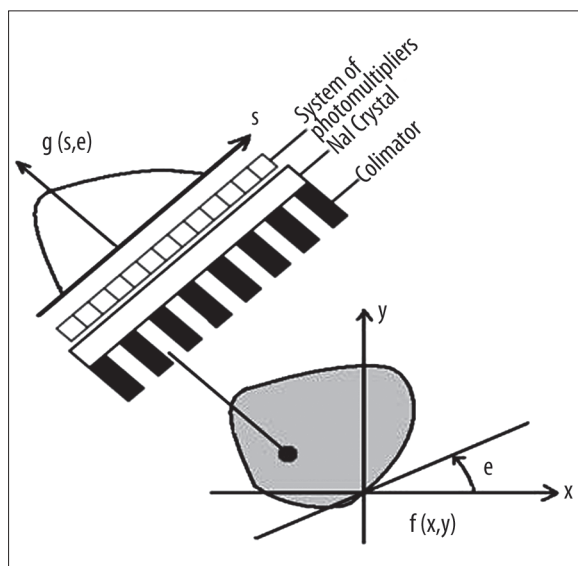


Figure 3. The principle of measurement projection in single photon emission computed tomography method (SPECT). Detector estimates activity of radiopharmaceutical passed along one closely named direct.

for reconstruction of topographic images registered by SPECT gamma camera.

Iterative methods of image reconstruction are used in emission tomography due to large errors in acquired data. They are aimed at most accurate estimation of algorithm coefficients that are contained in a linear equation $g=A \times f$, with g being a vector of a value in the sinogram, A – fixed matrix, f – unknown vector of a pixel value in the reconstructed image [17,19].

Another advancement in computer technology used, among others, in nuclear medicine is the application of a new OSEM algorithm (Ordered Subset Expectation Maximization), which is a modification of the MLEM algorithm [20,21]. Iterative OSEM method, in combination with Fourier filtering, reduces noise better than FBP, and the reconstructed topographic images are improved in regard to quality and clarity [22].

Filters: Metz, Weiner and Butterworth

An integral part of the image reconstructed with the back-projection method is the choice and implementation of an appropriate filter for obtaining the most accurate reflection of the acquired image of the diagnosed organ.

The first filter used for image reconstruction with SPECT technique was the Metz filter [23,24], defined in terms of frequency $M(v)$ as:

$$M(v) = \frac{1 - [1 - MTF^2(v)]^x}{MTF(v)} \quad (3)$$

where:

MTF – function modulating data transmission;

x – coefficient determining the range.

Another filter used in SPECT image reconstruction is the Wiener filter, a two-dimensional filter of the Fourier area [23,25]:

$$W(f) = MTF^{-1} \times MTF^{-2} / (MTF^2 + N/O) \quad (4)$$

where:

$W(f)$ – filter value as a function of spatial frequency;

MTF – function modulating data transmission;

N – noise power spectrum;

O – object energy spectrum;

Weiner filter (4) configured in such a manner serves the following functions: improves resolution as the reverse MTF and reduces noise as a low-pass filter.

Another filter applied in single photon emission tomography is the Butterworth filter, which is an example of a smoothing filter [26]. Similar to the Metz filter, Butterworth is defined in respect to frequency $B(v)$:

$$B(v) = \frac{1}{\left[1 + \left(\frac{v}{v_c}\right)^n\right]^{1/2}} \quad (5)$$

where:

v – frequency;

v_c – cut-off frequency determining the point where function reaches 0.

Conclusions

In the context of contemporary imaging modalities (CT, MRI), radioisotope diagnostic examinations of heart muscle, due to their non-invasiveness, are to a great extent irreplaceable in predicting cardiovascular events. The advantage of SPECT over other diagnostic methods comprises the possibility of assessing regional blood flow distribution in the myocardium and determining left ventricular functional parameters in gated SPECT of the heart (GSPECT) such as: ejection fraction, index of systolic wall thickening.

In single photon emission tomography there is a constant search for new solutions that would lead to quality improvement of organ imaging and shortening of the study time. An example of such solution was the introduction of a two-headed rotating camera into radioisotope diagnostics of myocardial perfusion, which significantly shortened the testing time for any single patient, as well as GSPECT, which beside assessing perfusion deficits in myocardial segments allows for obtaining additional clinical information regarding volume and ejection fraction of the left ventricle, myocardial contractility and systolic wall thickening index.

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