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# The use of multi-energy photon emitters in 3D SPECT reconstruction

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ABSTRACT

Several regularly used tracers in SPECT imaging are multi-energy photon emitters, which emit gamma photons at different energy levels. This study introduces different alternative reconstruction methods with attenuation correction and detector response compensation that enable the use of projection images generated by multi-energy photon emitters. The suggested alternative reconstruction scenarios are compared by simulation studies. The applied tracer was Gallium-67 with three photopeaks. Non-homogeneous attenuation medium and distance dependent spatial resolution (DDSR) of the parallel imaging device was modelled in the study. All the reconstruction algorithms compensated the energy dependent nature of the above two phenomena, in a different way. These suggested reconstruction scenarios differ in data acquisition strategy (i.e. summing up all energy windows into one projection image series or storing them separately) and in the energy dependent calculation of the forward projection during reconstruction. The presented reconstruction strategies have been compared using different mathematical phantoms such as a ring phantom in inhomogeneous attenuating medium, the Derenzo phantom, and the NCAT phantom.



## 1. Introduction

Single Photon Emission Computed Tomography (SPECT) is a widely used nuclear imaging technique for functional imaging of the human body, as well as pharmacological research in small animals [1]. During examination, a radiotracer is introduced into the body, that will process the labeled molecule as usual. Depending on the medical use, the radiotracer will be concentrated on parts of the body undergoing disease inspection. The radionuclide generates a gamma ray during decay, which usually leaves the body. Rotating gamma cameras capture these gamma photons, producing a 2D projection image set. These projection image measurements are used to reconstruct the 3D distribution of the radiotracer in the body.

Several SPECT radiopharmacies are applied in clinical applications for investigating human biological functions. Compounds with specific biological functions in the body are labeled with different isotopes. Technetium-99m ($^{99m}$TC) is the most commonly used isotope, that has a single emission energy peak value at 140.5 keV. $^{99m}$TC labeled perfusion agents such as sestamibi and tetrofosmin distribute in the myocardium proportionately to the myocardial blood flow and are used to study cardiac ventricular function and myocardial perfusion. Myocardial perfusion SPECT imaging has an important role in diagnoses of known or suspected coronary artery disease [2–5]. $^{99m}$TC-Methyl diphosphonate (MDP) is used for evaluating bone metastases. For functional brain imaging $^{99m}$TC labeled hexamethylpropylene amine oxime (HMPAO) allows imaging of regional cerebral blood flow and provides diagnostic information for patients with cerebrovascular disease [6].

Other gamma emitting isotopes with different energy emission characteristics are also used in clinical practice. For example Indium-111 ($^{111}$In) has two useful principal emission energy peaks in the SPECT detector range, 171.3 keV with 90% abundance and 245.4 keV with 94% abundance and is used in oncology for prostate cancer detection [7]. Gallium-67 ($^{67}$Ga) has several decay energies, from which there are three principal emission peaks: 93.3 keV with 38% abundance, 184.6 keV with 21% abundance and 300.2 keV with 17% abundance. Gallium citrate accumulates in primary and metastatic tumors and in inflammations that can be the cause of a fever of unknown origin [8]. Therefore, beyond the most often used $^{99m}$TC there are several important radioactive isotopes with multiple energy peeks that are regularly applied in clinical practice.

There are several physical phenomena that make SPECT image reconstruction challenging. Gamma rays are attenuated and scattered in the body, the detector has a non-linear, depth dependent

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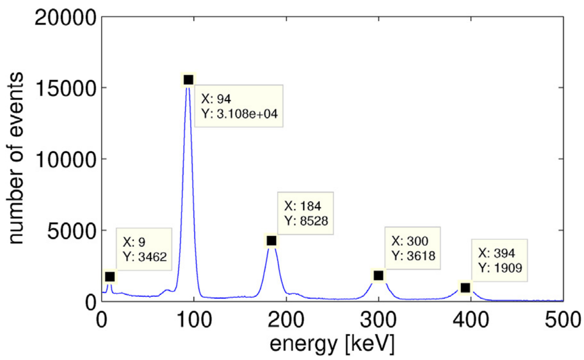


**Fig. 1.** Energy histogram of a simulated capillary (distance 100 mm).

resolution, furthermore statistical noise and background activity may degrade the measured projection images as well. These effects can be modeled and compensated for in iterative image reconstruction algorithms to improve image quality. In case of isotopes, emitting gamma photons at multiple energy peeks, being used in SPECT imaging, it is essential to collect events in every energy range in order to achieve better image statistics. However, the attenuation effect and the detector's Point Spread Function (PSF) characterizing the depth dependent resolution (DDSR) is a function of the gamma photon's energy, thus every principal energy peak has to be considered during the image reconstruction.

### *1.1. Goal of the research*

The aim of this study was to investigate the impact of using more than one energy peak of the tracer during OSEM iterative SPECT reconstruction with attenuation correction and DDSR compensation. The basis of this research is our previous reconstruction algorithm, that was designed to work with single-energy photon emitters, especially $^{99m}$TC [9]. The main question investigated in this study is whether it is worth it to combine the projection sets of the photopeak windows or not in order to improve our current iterative reconstruction algorithm. In previous studies similar multi energy SPECT reconstruction methods were investigated, however, without considering the effect of the distance dependent spatial resolution of the detector [10].

Our current implementation Szlávecz et al. [9] involves gamma photon attenuation and distance dependent detector blurring in the forward and backward projection of the reconstruction algorithm but does not correct for Compton scattering. This study does not focus on scatter correction, perfect scatter correction was assumed. This way we can clearly investigate the effect of multi energy SPECT reconstruction on DDSR compensation and attenuation correction methods. We are aware of that scatter correction is an important factor in quantitative SPECT imaging, thus scatter correction for multi energy emitters will be investigated in future studies.

In Section 2 an overview will be given about the multi energy SPECT reconstruction algorithms applied in this study. The effect of multi energy reconstruction strategies are studied by using different mathematical phantoms. The reconstruction results of these experiments are provided in Section 3. The comparison of the reconstruction results is given in Section 4. The main outcomes of the study are summarised in the last section.

## 2. Methods

First in this chapter the calibration method of the PSF of the detectors is introduced. Second the algorithms used for SPECT reconstruction are discussed followed by the description of their implementation. In the last subsection of the chapter the details of the multi-energy reconstruction strategies applied in the study are given.

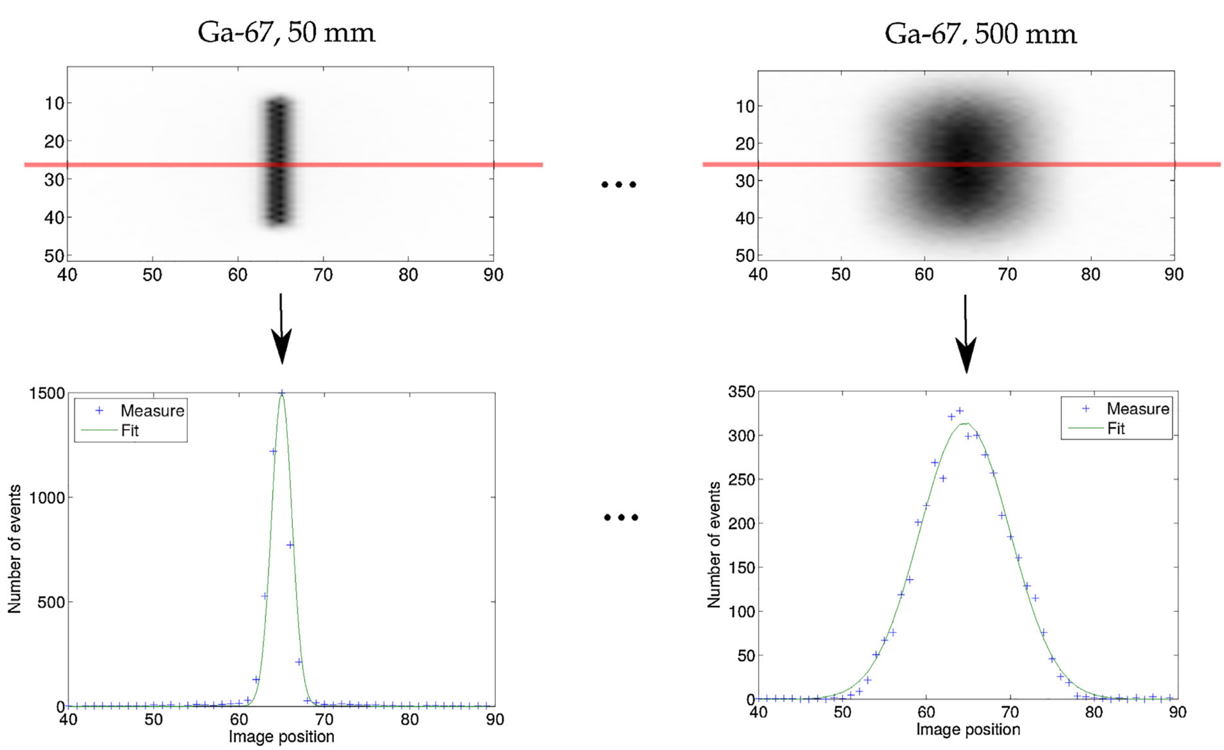


**Fig. 2.** DDSR calibration procedure: a $^{67}$Ga isotope filled capillary is placed in front of the camera and a planar image is acquired in several distances. The top row shows the result images at distance 50 mm on the left and 500 mm on the right. On the bottom row the Gaussian fit on the highlighted line profile of the image is shown. The pixel size is 3 mm.