Multi-peak multi-isotopes myocardial SPECT: It's easier said than done

C. Marcassa, MD,^a and O. Zoccarato, PhD^b

^a Maugeri Clinical and Scientific Institutes, IRCCS, Cardiology Department, Scientific Institute of Veruno (NO), Veruno, Italy

^b Maugeri Clinical and Scientific Institutes, IRCCS, Nuclear Medicine Department, Scientific Institute of Veruno (NO), Veruno, Italy

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A FEW HISTORICAL NOTES

Once upon a time, to study myocardial perfusion there was 201-thallium.¹ Things were easy: one isotope-one photo-peak, the 70 KeV. Moving from planar imaging to SPECT emphasized the limited count density of 201-thallium acquisitions. In an attempt to increase images count density, dual-energy windows acquisitions were implemented, including the second 201-thallium photo-peak at 167 KeV; this allows for an approximately 15% increase in count density.² Again, things were still quite easy: one single isotope-two peaks.

At the end of 80, several studies assessed the value of 111In-labeled antimyosin monoclonal antibody to detect the location and extent of myocardial injury.³ Simultaneous dual-isotopes acquisitions were proposed, using a dual-energy windows settled at 70 KeV (201-thallium) and 247 KeV (111In). Things were still non complicated, because of a very limited cross-talk of 201-thallium and 111-Indium each other.

In the same period, 99mTc-labeled perfusion tracers became available to assess myocardial perfusion. The 140 KeV photo-peak is ideal for SPECT imaging. Several dual-isotopes (201-thallium and 99mTc-tracers)

protocols were proposed.⁴ The original protocol uses Tl-201 for rest imaging, followed by Tc-99m sestamibi for stress acquisitions, providing the best performance of both tracers for the assessment of myocardial viability (201-Thallium) and ischemia (99mTc); an alternative protocol utilizes stress first with 201-Thallium and the rest study with 99mTc after.⁵ Ideally, a simultaneous acquisition of 201-thallium and 99mTc studies should be achieved, saving imaging time and increasing patient comfort and throughput. Moreover, acquiring two isotopes in one single scan potentially reduces errors caused by images misalignment.

However, despite the higher count density of 99mTc, the limited energy resolution of the traditional Anger cameras is responsible of the significant (approximately 27%) cross-talk of counts originating from the Tc-99m peak into the Tl-201 window,⁶ causing a possible overestimation of both ischemia and viability. Thus, separate-acquisition was the commonly used imaging modality.

Another type of dual-isotopes imaging involve 99mTc-tracers (140 KeV energy-window) and 123I-tracers (159 KeV energy window): e.g., BIMPP and MIBG. Also in this case, a significant cross-talk between the different photo-peaks and a partial overlap of the main peaks degrading image quality is present.

The arrival on the market of the new solid state detectors (the cadmium zinc telluride (CZT) systems), with their higher energy resolution, put a renewed interest in the simultaneous acquisition of two different isotopes and tracers.

THE CROSS-TALK PROBLEM AND THE PROPOSED SOLUTIONS

The cross-talk effect, mainly the downscatter of the higher peak into the lower resulting in the contamination in one isotope's energy window due to the detection of

Reprint requests: C. Marcassa, MD, Maugeri Clinical and Scientific Institutes, IRCCS, Cardiology Department, Scientific Institute of Veruno (NO), Via Per Revislate 13, 28010 Veruno, Italy; claudio.marcassa@icsmaugeri.it

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Table 1. Isotopes used in myocardial SPECT imaging and possible combination protocols

Isotopes	Isotope photo-peak (KeV)	
201Tl	69;167	
99mTc	140	
123I	159	
Combinations	Relative contamination	
	Isotope 1 → 2 (%)	Isotope 2 → 1 (%)
201-Tl:99mTc ⁷	12	25
99mTc:123I ⁸	4.7	40.7
201-Tl:123I ⁹	14	10

The isotopes photo-peak and relative contaminations in their combinations are reported

the photons from the other isotope, affects the attempts of acquiring two different tracers in one single shot since the beginning. In the case of simultaneous 201-thallium and 99mTc, 99mTc photons scattered in the body and lead X-rays created in the collimator fall within the 201-thallium energy window. In the case of 123I and 99mTc imaging, the photo-peak energies are close together: the primary photons of 123I and its down scattered photons would be detected in the 99mTc energy window, and the primary photons of 99mTc may be contained in 123I window as well. Finally, a small spillover fraction of 201-Thallium into the 123I energy window also occurs. (Table 1).⁷⁻⁹

Theoretically, to make it possible an accurate simultaneous imaging of multiple isotopes, two ways can be considered: to have detectors with better energy resolution and/or employ complicated scatter and cross-talk correction methods.

Several cross-talk correction methods have been proposed, that can be roughly grouped in multiple-windows-based or deconvolution-based methods.¹⁰

In the three-window technique, the most-used multiple-window method, a main window centered at photo-peak energy and two subwindows on both sides of the main window are set for each photo-peak, and the counts of these windows are measured for each pixel in each planar image. Then the count of the scattered photons included in each main window is estimated from the counts for the subwindows by a linear interpolation and is subtracted from that of the main window.¹¹⁻¹³ Despite such an approach does not take into account the differences in the spatial distribution between cross-talk photons in different energy windows, the three-window method yields good performance, and its popularity is due to the speed, ease of implementation, and accuracy in correction for self-scatter, as well as for cross-talk

Table 2. Energy resolution (FWHM in the primary photo-peak) in conventional Anger camera and CZT systems

Isotope	Anger camera	CZT detector
99mTc	9.5% (13.3 KeV)	5.4% (7.6 KeV)
201Tl	13.4% (9.4 KeV)	11.7% (8.2 KeV)
123I	9.0% (14.3 KeV)	5.8% (9.2 KeV)

with many combinations of isotopes.¹⁴ However, when the two photo-peaks are close each other, due to the energy resolution of the system and the emission energies of the isotopes used, the inclusion of un-scattered photons in the high scatter window occurs (e.g., 123I vs 99mTc).

In deconvolution methods, a conventional energy window is used, and the scattered photons are removed from measured photons by a deconvolution process, where the distribution of scattered photons within a given photo-peak is based on the assumption that the scattered image can be represented as a convolution of the photo-peak image with an appropriate blurring kernel. Parameters of this blurring kernel can be determined experimentally or through Monte-Carlo simulations.¹⁵ This method can be modified to facilitate correction for cross-talk.¹⁶⁻¹⁹

All this methods suffer from the intrinsic limitation in the energy resolution offered by conventional Anger cameras. The newest generation cameras take advantages of the increased energy resolution of cadmium zinc telluride (CZT) cameras versus conventional cameras (approximately + 30%) (Table 2)²⁰ to speed up the

interest in dual-isotope imaging (^{99m}Tc and ^{123}I ; ^{99m}Tc and ^{201}Tl , or ^{201}Tl and ^{123}I),²¹ and particularly in proposing a simultaneous acquisition of dual-isotope studies.^{22–24}

In this issue of the Journal, Songy et al. assessed the feasibility and clinical efficacy of simultaneous dual-isotope acquisition for myocardial perfusion imaging with a CZT camera, in a group of 117 patients.²⁵

The Authors applied a personalized three-window method: one windows was fixed on the main ^{201}Tl -thallium and ^{99m}Tc photo-peak, and a 3rd window was positioned at $100\text{ keV} \pm 10\%$. A weighting coefficient of 0.75 (previously determined experimentally) was then applied to this downscattered image, and the weighted image was subsequently subtracted from the ^{201}Tl -thallium image. This is not, however, a true triple-window method,¹⁴ were three energy windows were positioned for each main photo-peak; nonetheless, it is considered the easiest for a widespread use in clinical applications.

The major point in this study is that, despite a better energy resolution of CZT detector, the fraction of downscatter of ^{99m}Tc into the ^{201}Tl window is still important, actually limiting the use of simultaneous dual-isotope acquisition in the clinical arena. Moreover, in 10% of cases an underestimation and in in 20% an overestimation of diagnosis occurs.²⁵

The Authors used a GE DNM 530c system; thus, the results do not necessarily apply to the other commercially available CZT system, the D-SPECT that, apart from the detector, has a different architecture and different iterative reconstruction algorithms and post-recon filters. The main message, however, remain: even with this technology, downscatter and cross-talk are still with us.

The issue of scatter and cross-talk correction exists since the beginning of nuclear cardiology imaging; several methods have been proposed, including combinations of different approaches.

The higher energy resolution of the new solid state detectors seems to offer some advantages toward a better application of these methods, particularly when the two main energy peaks are distant enough (eg, ^{201}Tl and ^{123}I). However, the physical phenomena of the interaction of gamma-ray with the matter are unavoidable and downscatter from the higher peak into the lower will always be present, as well as partial overlap of the main energy peaks when close enough each other.

Additional studies, like that by provided by Songy et al are welcomed and necessary to increase our knowledge in this field, in order to push toward new correction methods for more complete, patient-tailored and faster myocardial SPECT studies.

Disclosure

Authors have nothing to disclose.

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