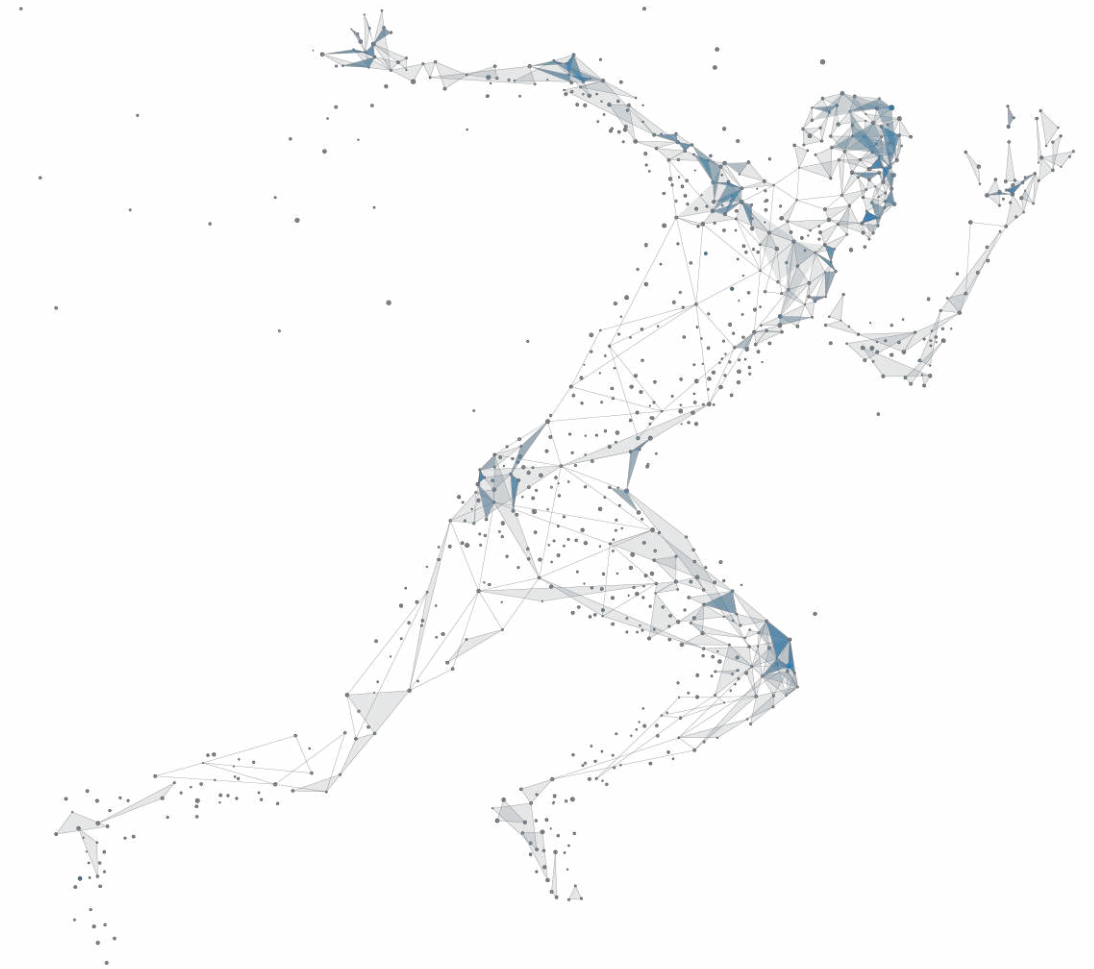
White Paper

Optimized Digital Gamma Camera Design – 360° CZT™ for Total Body Imaging



Optimized Digital Gamma Camera Design – 360° CZT™ for Total Body Imaging,

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Introduction

In 2018, Spectrum Dynamics introduced a Cadmium-Zinc-Telluride (CZT) based general purpose SPECT/CT scanner. The VERITON-CT® SPECT/CT Series include diagnostic 16 or 64 slice CT capabilities. The unique 360º CZT™ design, more closely resembling a PET ring gantry than traditional dual head nuclear camera, in many ways is an adaptation of their earlier D-SPECT® cardiac digital design. As the D-SPECT scanner focuses on close detector proximity to the patient optimized for cardiac imaging, VERITON uses a similar strategy using telescopic detectors to establish the optimal minimum source to detector distance. Similar swiveling detector assemblies, acquisition modes and reconstructions, as well as several new capabilities added to VERITON, maximize the impact of 360º CZT in routine clinical imaging. Both the D-SPECT and VERITON scan acquisitions are always 3D offering full tomographic detail.

Figure 1: Spectrum Dynamics' D-SPECT dedicated cardiac system, VERITON general purpose SPECT and VERITON-CT hybrid SPECT/CT systems.

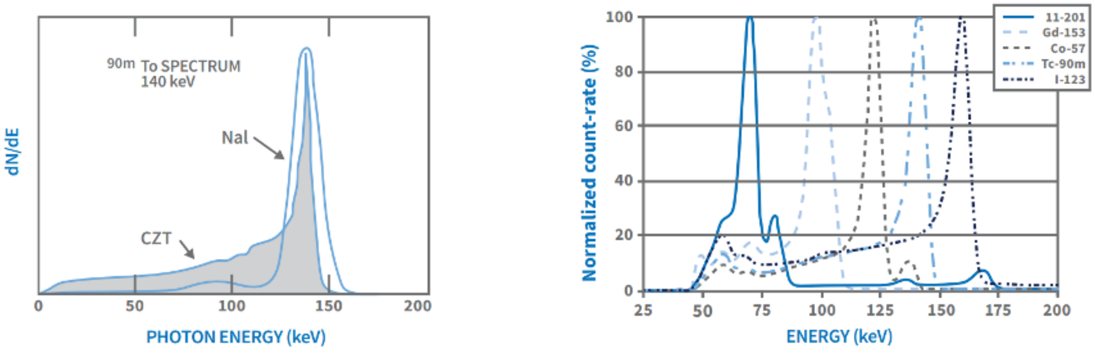
The incremental clinical value of direct digital conversion with CZT detector technology as compared to the conventional Anger camera design has been extensively reported in the scientific literature [1,2,3,4,5]. While the abundance of publications largely categorizes scanners with CZT detectors as a group, the specific impact of varying detector design and geometry may not be as broadly understood. CZT detectors themselves are only one of many key enabling components of these designs.

Both D-SPECT and VERITON systems integrate four different innovative technologies:

1. CZT direct conversion detectors with pixel registered parallel hole tungsten collimation
2. Optimal geometry of detection: for cardiac using a fixed 90° configuration (D-SPECT) and for organ or body using 360° body adaptive detection (VERITON)
3. Swiveling scan operation
4. Advanced image reconstruction and processing

Why CZT?

In an Anger camera with a Sodium Iodide (NaI) scintillator, gamma emitted photons are first converted into visible light photons and then into electric signal using photomultiplier tubes. This cascade of conversions, each with its non-ideal transfer function and noise, significantly reduces the overall detection efficiency. In digital cameras with CZT modules, direct conversion of a 140 keV gamma photon produces approximately 30,000 electrons. This is a 20-fold increase compared to that produced by a scintillating NaI crystal [Imbert]. One of the most significant benefits is that energy resolution is improved by a factor of 2, compared with conventional Anger cameras. This improvement is a key factor in distinguishing between scattered and non-scattered radiation and between energy peaks in a multi-isotope scan (Figure 2).



Barone-Rochette et al. JNC 2015

Erlandsson et al. Phys Med Biol 2009

Figure 2: With CZT detection energy resolution is improved by a factor of 2 compared to NaI detectors (Left). The reduced photopeak enables narrowing of the acceptance window and rejects a larger portion of scattered photons which degrade spatial resolution. In the same way, improved energy resolution enables differentiation between different isotopes in multi - isotope scans [Ben-Haim] (Right).

Why is geometry of detection so important?

The *geometry of detection*, defined by the distances between the detectors and the body, determines the actual number of detected photons and the spatial accuracy of their source estimation within the patient's body. Radiation from a radioactive source is emitted *isotopically*, i.e. with equal intensity in all directions [6]. At distance r from a source point the radiation passes through an imaginary sphere with surface area $4\pi r^2$. Thus, the flux at distance r decreases as $1/r^2$. This behavior is known as "the inverse square law". For this reason, both the D-SPECT and VERITON scanners were designed to position the detectors as close as possible to the patient's body to increase photon collection efficiency (i.e. *tomographic sensitivity)* which improves the spatial accuracy of the reconstructed image [4]. The tomographic sensitivity determines the imaging time and the activity that needs to be injected. In this case the improved tomographic sensitivity provided with the combination of CZT detection and minimal source to detector distance allow for a significant reduction of scan time or activity dose by a factor of 2-3x depending on the protocol and patient's size.

The process to achieve this ideal geometry of detection however differs between the D-SPECT and VERITON. The D-SPECT gantry head contains 9 columns of CZT detector assemblies and is positioned by the technologist directly against and conforming to the anterior chest wall of the patient [4]. There is no perceivable motion to the patient once the system is positioned.

The VERITON detectors, borrowing from the robust D-SPECT detector design, are longer along the Z axis, using more CZT modules and corresponding collimation. Each of the 12 detector assemblies are attached to a telescoping robotic arm that enables each detector to move in radial and circular directions toward and around the patient's body (Figure 3). These arms contain proximity sensors that set the detectors as close as possible to the patient's body to provide the maximum collection of photons. This design provides two major advantages over dual head cameras with flat detectors. The first advantage is 100% utilization of detector's surface while with dual head cameras only a part of the detector surface is used (Figure 3). The second advantage is that in VERITON, all detectors are closely positioned to the body’s surface while in dual head camera detectors a large portion of the detectors are far away from body's surface. Figure 3 highlights the importance of the geometry of detection and demonstrates VERITON's advantages over dual head cameras with flat panel geometry.

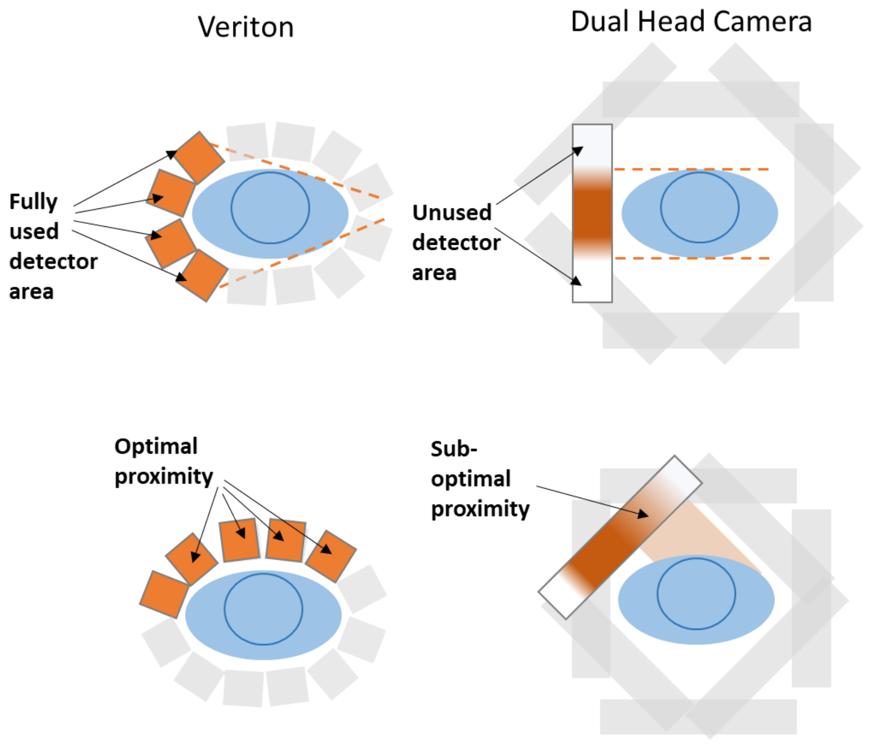


Figure 3: Importance of the *geometry of detection*. For optimal *tomographic sensitivity* with reduced scan time and injected activity, the detector's area should be in full usage and as close as possible to the body. VERITON was designed to achieve that goal and thus has a superior sensitivity compared to dual head camera design (conventional or CZT).

As mentioned, when comparing the tomographic sensitivity of Spectrum's CZT based systems to Anger cameras, experiments have found that it is possible to decrease acquisition times or injected activity by a factor of 2-3, leading to significant improvements in terms of patient comfort (less patient motion) and radiation burden. But tomographic sensitivity could further be improved by a factor of 5-6 when using the exclusive scan pattern called focus mode enabled by a swivel scanning approach.

What is a swiveling scan and why use it?

It is a well-documented tradeoff that any benefit of improved spatial resolution obtained by increasing collimation length is offset by a reduction in sensitivity, and vice versa [7]. With only the variable of collimation, high sensitivity and high spatial resolution cannot be obtained at the same time. The *swiveling scan* strategy was invented to overcome this limitation and allow the use of high-sensitivity collimators while simultaneously obtaining high spatial resolution. During acquisition, each of the detectors swivel on their axis and scan the prescribed field of view (FOV), collecting photons from several viewing angles incremented by a few degrees throughout the scan. This allows the body to be viewed from thousands of different viewing angles. Each viewing angle contributes unique spatial information on the scanned object. The benefit from a mathematical perspective is that each view contributes an equation to the reconstruction algorithm. More equations mean more spatial details that translate to a higher final spatial resolution image. In combination with tungsten collimation this detector design spares the complexity associated with the need to exchange the collimators for different imaging protocols. Therefore, Spectrum's design simplifies that patient's setup and overall workflow.

From a clinical perspective the swiveling motion creates the flexibility for individualized scan patterns as well. A standard approach uses a full FOV acquisition, where the detectors evenly swivel across the entire scanner FOV. A more tailored focus acquisition mode enables the detectors to align towards a user specified region of interest, preferentially acquire and weight image data from that area during reconstruction. Focused scanning is a highly purposeful and exclusive design element of the D-SPECT and VERITON enabled by the swiveling scan approach. This strategy allows for significantly more spatially shifted projections of the scanned organ in order to generate an enhanced resolution image using a dedicated iterative reconstruction algorithm. Focus scan mode has three main benefits:

1. Creates a personalized acquisition, optimized for patient specific anatomy
2. Increased tomographic sensitivity in the focused area for reduced scan time or injected activity.
3. Improved spatial resolution in the focused area as more samples are obtained per unit of volume.

In a focus mode acquisition, a short pre-scan is performed from which the user selects a region of interest. The region of interest and background are assigned weighted priorities with preference given to the assigned region. This allows for improved image quality in the focused area without omitting the background information. Protocols for both D-SPECT and VERITON are set by the user with full or focused FOV acquisitions and have proven ideal for the imaging of certain organs.

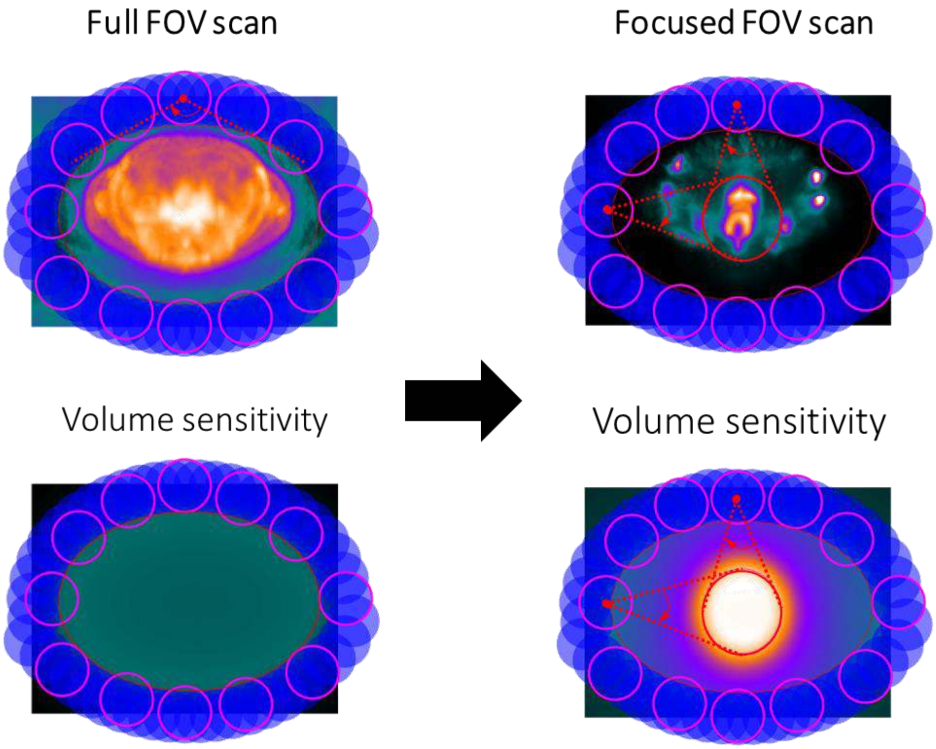


Figure 4: Demonstration of focus mode.

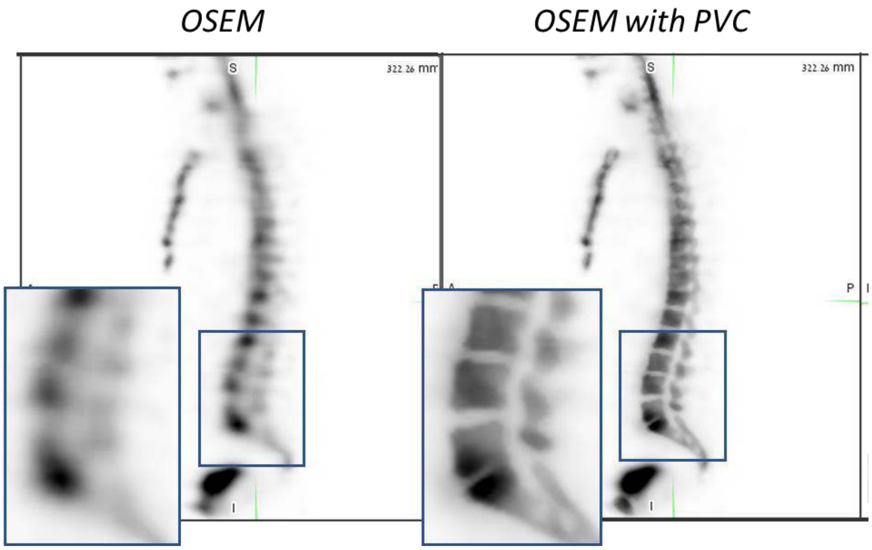
The ability to perform focused imaging plays an important clinical role in the imaging of small structures and has been shown on the D-SPECT to be an effective means by which to perform imaging of myocardial flow reserve (MFR) [8,9]. Given the large detector surface and slow rotation of the classic dual head design, conventional NaI systems are not capable of the temporal resolution needed for dynamic imaging of MFR. The D-SPECT was the first system able to overcome this challenge. While traditional myocardial perfusion imaging (MPI) SPECT has relatively high sensitivity [10,11,12], it has the potential to underestimate the true level of disease (low specificity). Adding MFR quantification to an MPI workup enables the clinician to potentially exclude the presence of high-risk CAD in the presence of normal MFR values [13]. PET imaging of MFR has shown that the presence of impaired function is common among patients with both ischemic and non-ischemic cardiomyopathy and is associated with major adverse cardiac events (MACE)[14]. In addition, MFR provides the potential to detect so called incidences of “balanced ischemia” and provides information about the possible presence of micro-vascular disease.

How do new advanced image reconstruction techniques impact image quality?

As a dedicated cardiac scanner, the D-SPECT systems include an exclusive proprietary model-based reconstruction. Gambihr et. al., described the simplified model of the left ventricle, located in a thoracic cavity similar to that used in the NCAT (NURBS-based cardiac thoracic) phantom which improves the scan resolution and image quality of the iterative reconstruction [4].

The VERITON and VERITON-CT systems are equipped with advanced image processing algorithms as well to ensure *state-of-the-art* image quality. Options include *OSEM iterative reconstruction with resolution recovery, attenuation correction (AC), scatter correction (SC)*, *partial volume correction (PVC)*, *high energy correction (HEC)* and more. Attenuation and Scatter Corrections are well studied and documented within functional imaging physics, but the less prevalent Partial Volume Correction and High Energy Correction approaches warrant further discussion [15,16,17].

As hybrid SPECT/CT systems increasingly become the standard of care around the globe, maximizing the use of the CT beyond anatomical localization, attenuation correction, or even basic diagnostic imaging becomes more relevant. Low dose CT scan data can also be used for Partial Volume Correction of the reconstructed image. The aim of PVC is to transfer the sharp edges provided by the CT into the SPECT image by constraining the activity to remain within the anatomical region edges during the reconstruction process. Figure 5 demonstrates the superior resolution of Partial Volume Corrected image compared to the regular image.

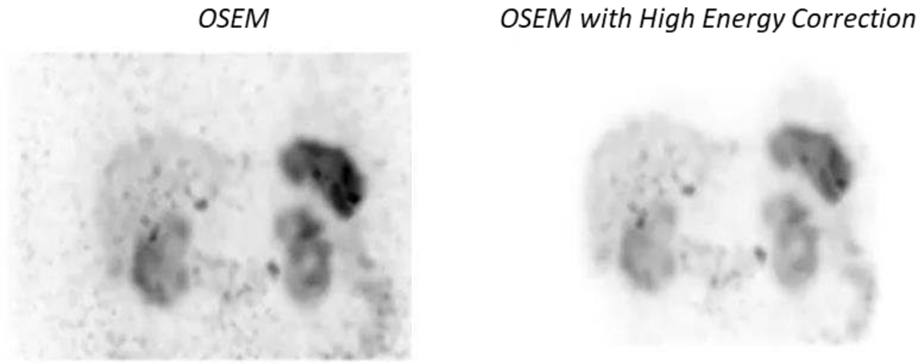


OSEM

OSEM with PVC

Figure 5: Demonstration of resolution enhancement using OSEM with partial volume correction (PVC) when compared to OSEM with resolution recovery. The sharp edges provided by the CT are used to increase the resolution in the reconstructed SPECT image.

Another advanced reconstruction option with VERITON series is *High Energy Correction (HEC).* This approach effectively deals with artifacts caused by high energy photons penetrating the collimators. The correction is performed by modeling the additive number of penetrating photons to those restricted by the collimation geometry in the iterative reconstruction process. Figure 6 demonstrates the reconstructed image with and without High Energy Correction.



OSEM

OSEM with High Energy Correction

Figure 6: MIP images of *OSEM with resolution recovery* and *OSEM* with *High Energy Correction* in *Indium-111* scan.

Conclusion

Continued technical innovation, as demonstrated by Spectrum Dynamics, is key to the growth of nuclear medicine as it introduces new ways to address complex imaging challenges without traditional tradeoffs. The unique approach to system geometry in D-SPECT and VERITON, leveraging digital CZT arrays, offers improvements to photon detection and image quality through advanced reconstruction techniques. Fully digital tomographic personalized exams, enabled by swivel scanning, increase physician confidence with improved photon capture resulting in better image contrast and lesion detection. Enabled by this digital transformation of SPECT, the appeal of faster scans, lower radiation dose, fully quantitative images and improved image quality offers real potential to bring more patients back to nuclear medicine along with continued industry investment.

References

1- Perrin M, Djaballah W, Moulin F, Claudin M, Veran N, Imbert L, Poussier S, Morel O, Besseau C, Verger A, Boutley H. Stress-first protocol for myocardial perfusion SPECT imaging with semiconductor cameras: high diagnostic performances with significant reduction in patient radiation doses. European journal of nuclear medicine and molecular imaging. 2015 Jun 1;42(7):1004-11.

2- Imbert, Laetitia, and Pierre-Yves Marie. CZT cameras: a technological jump for myocardial perfusion SPECT. 2016: 894-896.

3- Ben-Haim S, Kacperski K, Hain S, Van Gramberg D, Hutton BF, Erlandsson K, Sharir T, Roth N, Waddington WA, Berman DS, Ell PJ. Simultaneous dual-radionuclide myocardial perfusion imaging with a solid-state dedicated cardiac camera. European journal of nuclear medicine and molecular imaging. 2010 Aug 1;37(9):1710-21.

4- Gambhir SS, Berman DS, Ziffer J, Nagler M, Sandler M, Patton J, Hutton B, Sharir T, Haim SB, Haim SB. A novel high-sensitivity rapid-acquisition single-photon cardiac imaging camera. Journal of Nuclear Medicine. 2009 Apr 1;50(4):635-43.

5- Mannarino T, Assante R, Ricciardi C, Zampella E, Nappi C, Gaudieri V, Mainolfi CG, Di Vaia E, Petretta M, Cesarelli M, Cuocolo A. Head-to-head comparison of diagnostic accuracy of stress-only myocardial perfusion imaging with conventional and cadmium-zinc telluride single-photon emission computed tomography in women with suspected coronary artery disease. Journal of Nuclear Cardiology. 2019 Jun 20:1-0.

6- Cherry SR, Sorenson J, Phelps ME, Methé BM. Physics in nuclear medicine. Medical Physics. 2004 Aug;31(8):2370-1.

7- Van Audenhaege K, Van Holen R, Vandenberghe S, Vanhove C, Metzler SD, Moore SC. Review of SPECT collimator selection, optimization, and fabrication for clinical and preclinical imaging. Medical physics. 2015 Aug;42(8):4796-813.

8- Ben-Haim S, Murthy VL, Breault C, Allie R, Sitek A, Roth N, Fantony J, Moore SC, Park MA, Kijewski M, Haroon A. Quantification of myocardial perfusion reserve using dynamic SPECT imaging in humans: a feasibility study. Journal of Nuclear Medicine. 2013 Jun 1;54(6):873-9.

9- Agostini D, Roule V, Nganoa C, Roth N, Baavour R, Parienti JJ, Beygui F, Manrique A. First validation of myocardial flow reserve assessed by dynamic 99m Tc-sestamibi CZT-SPECT camera: head to head comparison with 15 O-water PET and fractional flow reserve in patients with suspected coronary artery disease. The WATERDAY study. European journal of nuclear medicine and molecular imaging. 2018 Jul 1;45(7):1079-90.

10- Fleischmann KE, Hunink MG, Kuntz KM, Douglas PS. Exercise echocardiography or exercise SPECT imaging?: A meta-analysis of diagnostic test performance. Jama. 1998 Sep 9;280(10):913-20.

11- Miller TD, Hodge DO, Christian TF, Milavetz JJ, Bailey KR, Gibbons RJ. Effects of adjustment for referral bias on the sensitivity and specificity of single photon emission computed tomography for the diagnosis of coronary artery disease. The American journal of medicine. 2002 Mar 1;112(4):290-7.

12- Stewart RE, Schwaiger M, Molina E, Popma J, Gacioch GM, Kalus M, Squicciarini S, Ai-Aouar ZR, Schork A, Kuhl DE. Comparison of rubidium-82 positron emission tomography and thallium-201 SPECT imaging for detection of coronary artery disease. The American journal of cardiology. 1991 Jun 15;67(16):1303-10.

13- Naya M, Murthy VL, Taqueti VR, Foster CR, Klein J, Garber M, Dorbala S, Hainer J, Blankstein R, Resnic F, Di Carli MF. Preserved coronary flow reserve effectively excludes high-risk coronary artery disease on angiography. Journal of Nuclear Medicine. 2014 Feb 1;55(2):248-55.

14- Majmudar MD, Murthy VL, Shah RV, Kolli S, Mousavi N, Foster CR, Hainer J, Blankstein R, Dorbala S, Sitek A, Stevenson LW. Quantification of coronary flow reserve in patients with ischaemic and non-ischaemic cardiomyopathy and its association with clinical outcomes. European Heart Journal–Cardiovascular Imaging. 2015 Feb 25;16(8):900-9.

15- Patton JA, Turkington TG. SPECT/CT physical principles and attenuation correction. Journal of nuclear medicine technology. 2008 Mar 1;36(1):1-0.

16- Pourmoghaddas A, Vanderwerf K, Ruddy TD, Wells RG. Scatter correction improves concordance in SPECT MPI with a dedicated cardiac SPECT solid-state camera. Journal of Nuclear Cardiology. 2015 Apr 1;22(2):334-43.

17- Hutton BF, Buvat I, Beekman FJ. Review and current status of SPECT scatter correction. Physics in Medicine & Biology. 2011 Jun 23;56(14):R85.