REVIEW ARTICLE

New Generation SPECT Cameras Based on Cadmium-Zinc Telluriide Technology

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Abstract

Despite recent developments in positron emission tomography technology, cardiac single photon emission computed tomography (SPECT) imaging continues to be the main stream of nuclear cardiology because of its high accessibility and wider clinical use. For SPECT imaging, cadmium-zinc telluride (CZT) based detectors have advantages over conventional Anger type detectors with more flexible camera design thanks to the small sized CZT detectors and high contrast imaging because of its high energy resolution. Approximately 15 years ago, CZT-based cardiac SPECT cameras became commercially available, resulting in great success in clinical practice. However, this was just the beginning of the CZT era. To date, CZT-based general purpose whole-body camera and 3 dimensional full-ring SPECT systems have been developed and become commercially available with promising initial results. Although there still are areas to be addressed before wider clinical use, the CZT-based technology may provide significant progresses in nuclear cardiology as new generation SPECT systems. Finally, newer materials for the semiconductor detectors are under investigation or development, suggesting that there will be more developments in cardiac SPECT technology.
Keywords: 3D full-ring SPECT, Cadimium-zinc telluride (CZT), SPECT
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Despite recent developments in positron emission tomography (PET) technology, cardiac single photon emission computed tomography (SPECT) imaging continues to be the main stream of nuclear cardiology because of its high accessibility and wider clinical use. For SPECT imaging, cadmium-zinc telluride (CZT) based detectors have advantages over conventional Anger type detectors. These include that 1) the small sized CZT detector enables flexible camera design such as a ring-configured SPECT system resulting in high sensitivity, which is achieved by direct conversion of gamma ray to electric signal, and high spatial resolution, which is achieved by small detector pixel size (2.46 mm), and that 2) the high energy resolution enables high contrast imaging. Therefore, CZT detectors have been applied to many SPECT imaging devices such as pre-clinical SPECT system, SPECT camera dedicated for cardiac imaging, whole-body SPECT system, and 3 dimensional (3D) full-ring SPECT system. The purpose of this review article was to review and discuss about various CZT-based SPECT systems in view of clinical utility and future perspectives.

Pre-clinical SPECT

It is conceivable that CZT detectors are especially suitable for pre-clinical imaging because of its small detector size. In fact, a couple of vendors developed such CZT-based SPECT systems. Figure 1 depicts a CZT-based SPECT/CT system (eXplore speCZT, GE Healthcare, Milwaukee, WI) designed for small animal imaging such as rats and mice (1). Using this system, electrocardiogram (ECG)-gated myocardial β-methyl iodophenyl-pentadecanoic acid (BMIPP) imaging in the rat was feasible as shown in Figure 2.

Cardiac SPECT

For clinical use, CZT technology was applied to SPECT systems dedicated for cardiac imaging. Currently, two SPECT systems are commercially available. One is MyoSPECT (ex. Discovery MM 530c (2), GE Healthcare, Milwaukee, WI) and the other is D-SPECT (3) (Spectrum Dynamics, Israel). Figure

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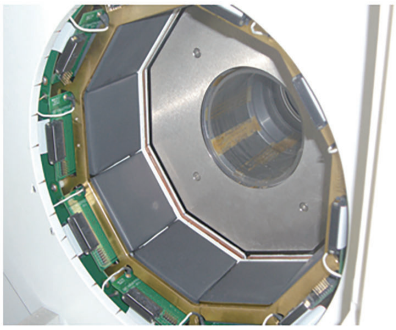
speCZT SPECT/CT



CZT detectors

Figure 1 The speCZT SPECT/CT system. The SPECT part is located in the front, and CT in the back (upper). The system has a stationary detector design, which consists of 10 CZT detectors surrounding field of view (bottom).

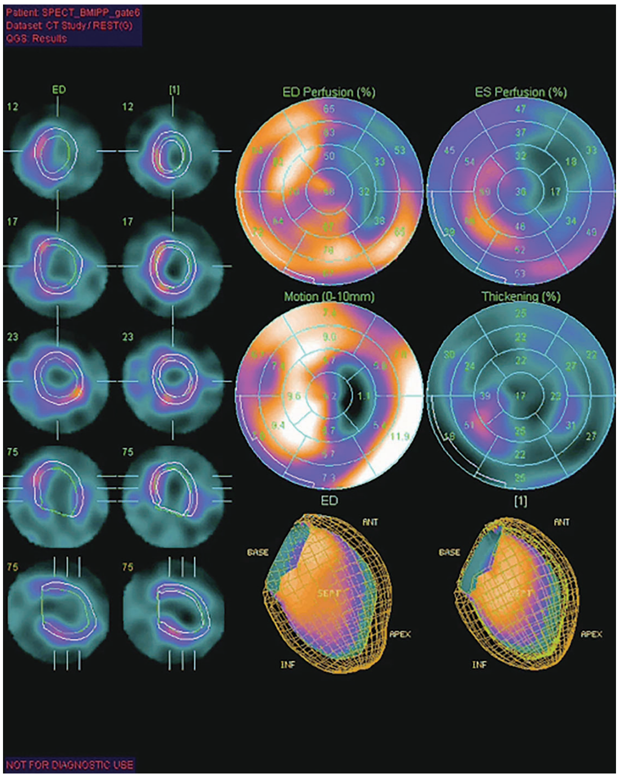


Figure 2 ECG-gated ^{123}I-BMIPP myocardial SPECT images of a rat with anterior myocardial infarction.

3 depicts a CZT-based cardiac SPECT with stationary detectors with a pin-hole collimator (Discovery NM 530c). Both SPECT systems have advantages over conventional SPECT in two ways. Firstly, fast imaging with short acquisition time or low dose imaging for low radiation exposure is feasible without loss in diagnostic performance as demonstrated in many studies (4–6). This was true when compared to diagnostic performance using conventional Anger SPECT (7). Secondly, myocardial flow reserve can be estimated by dynamic SPECT imaging capability (8, 9). A limitation of flow reserve measurement using SPECT is, however, the lack of ideal Tc-99m labeled flow tracers particularly for high flow rates. Because of this, accurate measurements of hyperemic flow is limited as compared to PET. Nevertheless, clinical significance of CZT-based cardiac SPECT is now well acknowledged and accepted in clinical practice.

Whole-body SPECT

With the success of CZT-based cardiac SPECT systems, a CZT-based camera for general purpose whole-body imaging has been developed. Discovery NM/CT 670 CZT (currently, NM/CT 870 CZT, GE Healthcare, Milwaukee, WI) is the only commercially available CZT-based camera for whole-body imaging. As illustrated in Figure 4, this system has 2 large field of view CZT-based gamma cameras equipped with 16-raw CT scanner.

Using this system, we tested whether fast planar imaging is feasible without loss in diagnostic performance, because this is the only CZT-based camera with true planar imaging capability. As expected, fast ^{123}I-MIBG planar imaging of as fast as 50 second acquisition was feasible without significant errors in measured heart-to-mediastinum uptake ratios (10). Similarly, fast whole-body bone imaging was also feasible (11). For cardiac tomographic imaging, fast ECG-gated myocardial perfusion SPECT as fast as 2 minute acquisition was feasible without significant loss in diagnostic performance, as shown in Figure 5 (12).

Another advantage of CZT detectors is its high energy resolution (5–6 % full-width at half maximum [FWHM]) as compared with conventional Anger detectors (8–10 % FWHM). On the basis of its high energy resolution, we tested the feasibility of simultaneous ^{99m}Tc-tetrofosmin (peak energy of 140 KeV) and ^{123}I-BMIPP (peak energy of 159 KeV) dual-isotope imaging in patients with acute myocardial infarction (13). A representative case example of ^{99m}Tc-tetrofosmin/^{123}I-BMIPP dual-isotope imaging is shown in Figure 6. As expected, a clear mismatch of myocardial distribution between

Figure 3 An example of CZT-based cardiac SPECT system (Discovery NM530c, GE Healthcare).

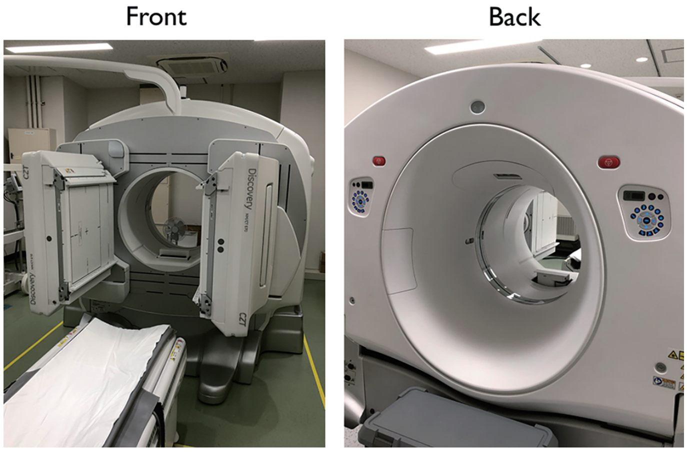


Figure 4 A CZT-based SPECT/CT system for whole-body imaging. The SPECT part is located in the front (left), and CT in the back (right).

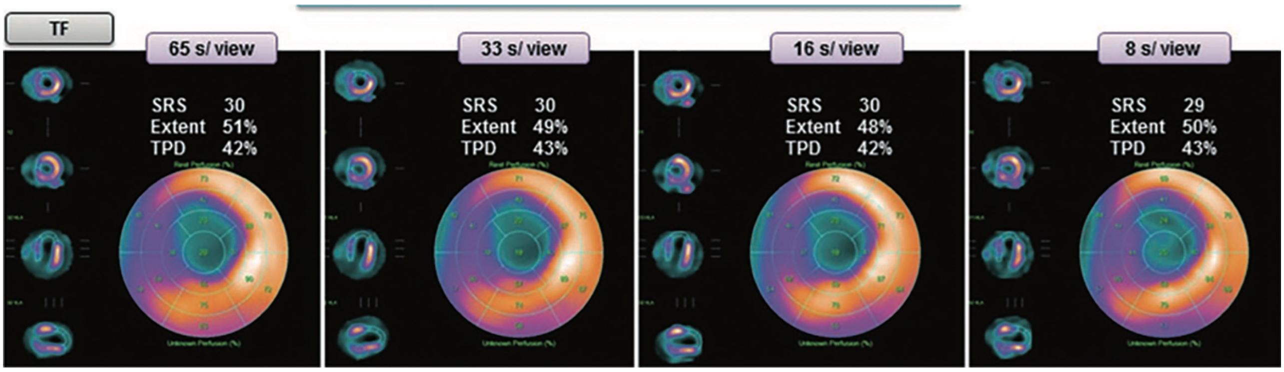


Figure 5 An example of fast ^{99m}Tc-tetrofosmin myocardial perfusion SPECT. Images of acceptable quality were obtained even with a very fast (8 s/view; 2 minutes) scan. Adopted from ref. 12.

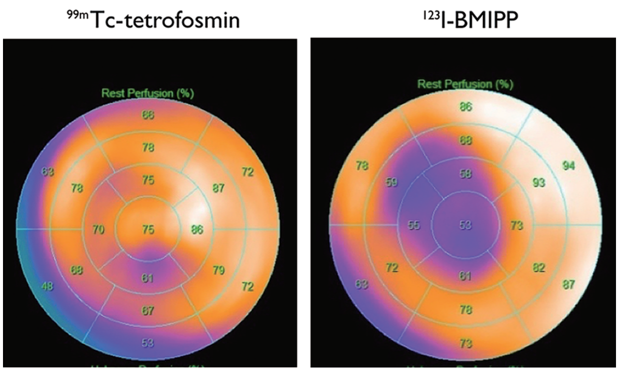


Figure 6 Simultaneous ^{99m}Tc-tetrofosmin/^{123}I-BMIPP dual-isotope SPECT polar maps in a patient with anterior myocardial infarction. Reduction in ^{123}I-BMIPP uptake as compared to ^{99m}Tc-tetrofosimin is seen in the anterior myocardial wall.

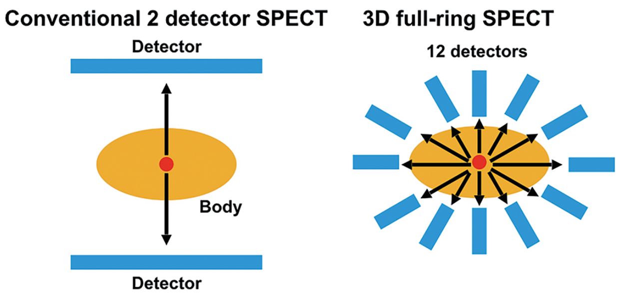


Figure 7 Configuration of 3D full-ring SPECT as compared to conventional 2 detector SPECT.

the two tracers was observed, suggesting the feasibility of simultaneous dual-isotope imaging even when the energy peaks of two tracers are close to each other.

3D full-ring SPECT

Recent advances in technology enabled development of CZT-based 3D full-ring SPECT systems, which was achieved because of small sized CZT detectors. Two such systems (StarGuide, GE Healthcare, Milwaukee, WI and Veriton, Spectrum Dynamics, Israel) are currently commercially available. Both systems have 12 movable small detectors surrounding FOV. This configuration has three advantages over conventional two detector SPECT systems (Figure 7). Firstly, higher sensitivity can be achieved thanks to more detectors than conventional systems (12 versus 2). Secondly, higher spatial resolution can be obtained because detectors can be more close to the target body. Finally, dynamic SPECT imaging is feasible to obtain, for example, myocardial flow

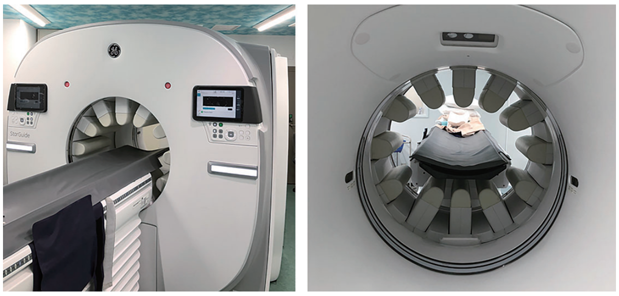


Figure 8 StarGuide SPECT/CT system.

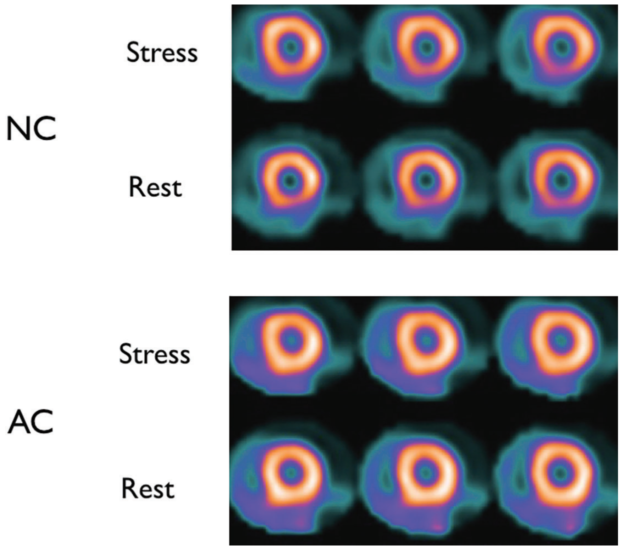


Figure 9 Myocardial perfusion SPECT images with and without CT-based attenuation correction. Non-corrected images (NC) are shown in the upper panel, whereas attenuation-corrected images (AC) are shown on the bottom.

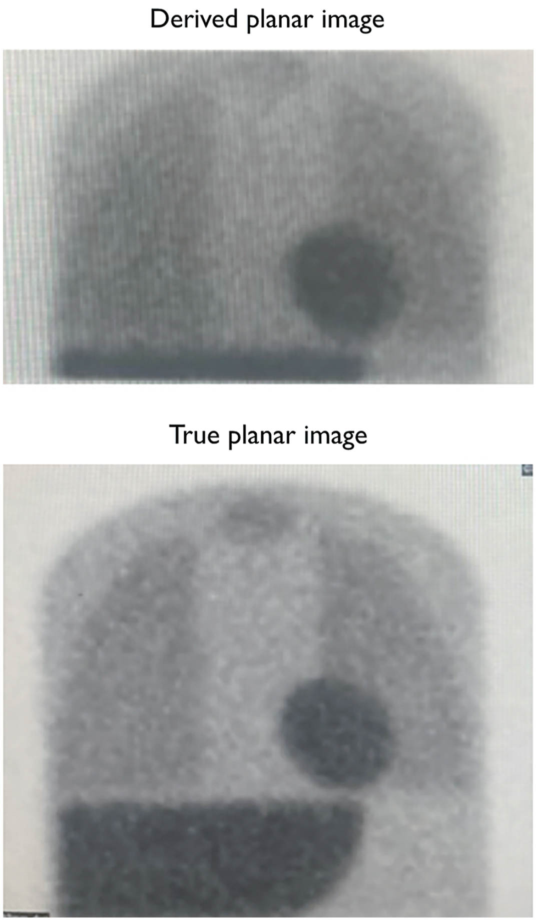


Figure 10 SPECT derived (upper) and true (bottom) planar images of ^{123}I-MIBG phantom.

reserve.

Figure 8 depicts one of such 3D full-ring SPECT systems (StarGuide, GE Healthcare). As aforementioned, this system consists of 12 movable small detectors for SPECT imaging together with a 16-raw CT. The detailed system performance has been reported elsewhere (14). According to that report, the system has the energy resolution of 5.3% FWHM for ^{99m}Tc, the volume sensitivity of 520 cps/MBq, and SPECT spatial resolution of 4 mm FWHM in all directions. Additionally, unlike SPECT cameras dedicated for cardiac imaging, attenuation correction is ready to perform owing the combined CT system. An example of attenuation corrected myocardial SPECT images using this system are shown in Figure 9.

A disadvantage of 3D full-ring SPECT is that planar imaging is not possible because its configuration is dedicated for SPECT imaging. This is not negligible because heart-to-mediastinum uptake ratios on ^{123}I-MIBG images, for example, is an important prognostic biomarker in heart failure patients (15). However, planar-like images (i.e., SPECT derived planar images) can be generated from projection data. An example of the SPECT derived planar image of ^{123}I-MIBG phantom (16) is shown in Figure 10.

Thus, CZT-based 3D full-ring SPECT is promising with high system performance and may provide significant progresses in nuclear cardiology as a totally new generation SPECT system. However, there are areas to be addressed before its wide clinical acceptance. Firstly, available clinical data are still limited because this is a rather new system. Secondly, softwares for data acquisition and processing such as those for dynamic imaging should be refined.

Beyond CZT-based detectors

With the great success of CZT-based SPECT cameras, newer materials for the semiconductor solid-state detector are under investigation or development. Of these, thallium bromide seems to be a promising candidate with high sensitivity and high energy resolution (17). Thus, we hope that such newer materials for the detectors will become clinically available in near future.

Conclusion

CZT technology is one of the most exciting developments in nuclear cardiology field. Approximately 15 years ago, CZT-based cardiac SPECT cameras became commercially available, resulting in great success in clinical practice. However, this was just the beginning of the CZT era. To date, CZT-based general purpose whole-body camera and 3D full-ring SPECT systems have been developed and become commercially available with promising initial results. Although there still are areas to be addressed before wider clinical use, the CZT-based technology may provide significant progresses in nuclear cardiology as new generation SPECT systems. Finally, newer materials for the semiconductor detectors are under investigation or development, suggesting that there will be more developments in cardiac SPECT technology.

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Conflicts of interest

The author has no conflict of interest.

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