J of Nuclear Medicine Technology, first published online October 5, 2020 as doi:10.2967/jnmt.120.254870

Introduction to the D-SPECT for Technologists: Workflow Using a Dedicated Digital Cardiac Camera

Robert D. Johnson,[1] Navkanwal Kaur Bath,[1] Jeffrey Rinker,[1] Stephen Fong,[1] Sara St. James,[2] Miguel Hernandez Pampaloni,[3] and Thomas A. Hope, MD[1,3]

1. Department of Radiology, San Francisco VA Medical Center, San Francisco, CA
2. Department of Radiation Oncology, University of California, San Francisco, San Francisco, CA
3. Department of Radiology and Biomedical Imaging, University of California, San Francisco, San Francisco, CA

Corresponding Author:
Thomas A. Hope, MD
Associate Professor in Residence
thomas.hope@ucsf.edu
San Francisco VA Medical Center

Abstract

The D-SPECT is a dedicated cardiac camera, which incorporates a solid-state semiconductor detector. This camera varies greatly from conventional SPECT/CT systems, which results in significant differences in patient imaging. This continuing education article focuses on the specifications of both SPECT/CT and D-SPECT camera systems, radiopharmaceutical dosing requirements, imaging workflows and some disadvantages of utilizing each camera system. When used properly, the D-SPECT system can provide high quality cardiac images using lower doses and faster exam times than conventional SPECT/CT systems.

Introduction

Coronary artery disease (CAD) is the leading cause of death in the United States (1). Myocardial perfusion imaging (MPI), using single photon emission computed tomography (SPECT) is one of the most frequently used diagnostic tools for patients at risk for CAD, and has significant prognostic value (2). Dedicated cardiac SPECT cameras such as the D-SPECT (Spectrum Dynamics, Haifa, Isreal) have been specifically designed for MPI studies. Equipped with cadmium–zinc–telluride (CZT)-based detectors, the D-SPECT camera has demonstrated superior image quality when compared to standard SPECT or SPECT/computed tomography (CT) cameras, while reducing patient and personnel radiation exposure and decreased imaging time (3).

Conventional SPECT/CT

SPECT imaging is based upon 50-year-old technology which consists of a collimator and a sodium iodide (NaI) crystal coupled to photomultiplier tubes. The gamma rays emitted from the patient post radiotracer injection, pass through the collimator, interact with the crystal, resulting in thousands of optical scintillation photons that are detected by the photomultiplier tubes. The role of the photomultiplier tubes is to convert the optical signal from the scintillation photons into an electronic signal proportional to the energy deposited in the crystal. The size of the NaI crystal typically range in thickness from 6.35 mm - 15.9 mm (4). For Tc99m labeled radiotracers, a thickness of 9.5 mm is preferred as it is able to stop 90% of the 140 keV photons incident on the crystal (4).

Most SPECT/CT cameras used for cardiac imaging use two detectors configured at 90° or 180° mounted on a gantry, although three detector systems are also used. In the practice of nuclear cardiac imaging, the preferred configuration of the dual detector system is 90°, as this increases the sensitivity of images and reduces the scanning time (4). Since the heart is positioned anteriorly in the left hemothorax, supine imaging begins at a 45° angle on the right anterior oblique and completes a 180° arc around the patient.

The gantry rotates while the detectors contour around the patient's chest as part of the setup process for image acquisition, and 64 images with 32 steps are typically acquired. Conventional SPECT cameras are equipped with low-energy/high-resolution parallel hole collimators; the role of the parallel hole collimators is to limit photons detected to those that are perpendicular to the detector, making tomographic image reconstruction possible. These same collimators, however, will stop more than 99.9% of photon as they are not incident on the holes of the collimator, resulting in a trade-off between spatial resolution and sensitivity. Due to this loss of sensitivity, acquisition times on the order of 20 minutes are required for SPECT studies (4).

The hybrid technology of SPECT/CT is used for myocardial imaging, with the CT in tandem with the SPECT system. All SPECT/CT studies are acquired sequentially, so it is important that the patient be in the exat same position during and between each scan (apart from normal tidal breathing). Undesirable movement by the patient will cause a misregistration of the SPECT and CT images. In addition to anatomic information, the CT component of SPECT/CT systems is used to perform attenuation correction (5) (Figure 2).

D-SPECT Equipment

Unlike the original SPECT technology that relied upon the pairing of scintillators to photomultiplier tubes, the D-SPECT detector uses semiconductor-based solid-state detectors that are constructed with CZT. When the photons interact with the CZT in the semiconductor, the incident gamma rays create electron pairs and an electrical signal is produced. The direct conversion of energy in the semiconductor solid state detectors are characterized by good energy resolution, and in clinical applications the energy resolution is reported to be better than 6% at 140 keV (5). Unlike other detectors (e.g. germanium), CZT operates at room temperature.

Though there are several CZT camera manufacturers, the focus in this review will be the D-SPECT system (Spectrum Dynamics, Caesarea, Israel). In the D-SPECT system there are nine individually rotating detector columns arranged on a stationary gantry in a curved configuration to accommodate the heart on the left side of the patient's chest (Figure 3). The size of each detector column is 40 mm wide (16 pixels) by 160 mm tall (64 pixels). Each detector column is comprised of CZT detectors which are aligned with square apertures of the parallel-hole tungsten collimator in front of them, with one CZT pixel for each square hole. Every detector column rotates at 110° independently of one another, allowing for hundreds of projections of varying angles of the heart to be acquired. The tungsten collimator has short holes (21.7 mm) and the square apertures of the collimator (2.26 mm) allow a higher percentage of photons to pass through compared to conventional low-energy high-resolution collimator, which typically have 35-45 mm x 1.5-2.0 mm holes. Due to the larger aperture size relative to the size of the collimator, there is an 8-fold increase in acceptance of incidental photon detection, compared to a conventional SPECT collimators (6). In the setting where the gantry is stationary and the detector columns rotate individually, the D-SPECT enables a list mode for dynamic acquisition. Due to geometry and sensitivity limitations, conventional SPECT systems typically cannot acquire dynamic data sets (6).

One of the unique aspects of the D-SPECT system, is that patients are imaged in a sitting position, and the patient can be positioned in an upright or supine position (Figure 1). An additional and important difference between the D-SPECT and a conventional SPECT/CT, is the absence of CT imaging for attenuation correction. Approaches to minimize attenuation artifacts are discussed further below.

Comparison in Image Quality Between Systems

In nuclear medicine, a gamma camera is used to produce an image and the quality of these images depend upon three factors: energy resolution, spatial resolution and sensitivity.

Energy resolution characterizes the ability of the system to determine the energy of the incident photons. In nuclear medicine, good energy resolution allows for the discrimination of low energy photons (that have already scattered in the patient) from higher energy photons that have had fewer interactions before depositing their energy in the detector. Energy resolution is reported as the full width at half maximum (FWHM) of a Gaussian fit of the energy profile, for a given energy. A Gaussian function is a function that represents the normal distribution, and the FWHM is the width of the energy profile where the measured energy is half of its maximum value. As energy resolution depends on the incident photon energy and will change depending on the radionuclide being imaged, the energy of the measurement is always reported. CZT has improved energy resolution compared to NaI, across the clinically relevant energy range, with an improvement in energy resolution of a factor of two or better (7).

Spatial resolution is the ability to separate distinct objects, where better resolution results in sharper, more detailed images. The spatial resolution of the D-SPECT system is 2.5 mm while traditional SPECT systems typically have a spatial resolution between 3.5-4.0 mm (4) (Table 1), owing to the geometry of the system and the small size of the individual detector elements.

Sensitivity is reported as the percentage of emitted photons from the patient that are detected by the SPECT system. Higher sensitivity of a system means that an image acquired in the same duration will have more counts and an improved signal-to-noise ratio. In the D-SPECT module, each detector column turns individually on its own axis and a greater number of photons pass through larger-hole collimators. This increases the sensitivity for the D-SPECT by 5-10 times over the traditional SPECT system (4). For conventional SPECT systems, sensitivity is rather low due to only a small fraction (10^{-6}) of photons being detected from the radiotracer activity due to absorption by the collimator (3) and the solid angle coverage.

Image quality on conventional SPECT cameras can be impacted by various artifacts. These artifacts are caused by a relative low number of photons emitted from the heart that are overwhelmed by the activity from the regions such as the intestines or biliary system. This can result in the ramp filter artifact where activity below the diaphragm results in either higher or lower activity in the inferior wall (4,8). Direct alignment with the heart, combined with D-SPECT's approximate 15.7 cm axial field of view (FOV) and its concentrated heart centric aiming, decreases the amount of acquired photons from extracardiac areas, minimizing this artifact. One risk with the smaller field of view with the D-SPECT, is that truncation artifact can occur if the heart is not within the FOV of the scanner (4).

Dosing Information

Studies show that the D-SPECT allows a lower administered activity to be injected to reduce radiation exposure, while providing diagnostic images performed with shorter acquisition times (Table 2). The American Society of Nuclear Cardiology protocol guidelines recommend 8-12 mCi for rest and 24-36 mCi for stress imaging for a one-day rest-stress protocol (9). In an article by Perrin et al, this was reduced to 3-7 mCi and 10-22 mCi on the D-SPECT (10), although this study used a stress-rest protocol. It should be noted that in the Perrin article, this dose range resulted in an acquisition time of 7.7 minutes at stress and 2.7 minutes at rest. By using the D-

SPECT the effective dose would be reduced from roughly 13 mSv using a standard SPECT to 8 mSv. Radiation exposure can further be reduced, particularly with obese patients, in upright positioning, which is helpful for interpreting, and use of stress-first imaging can eliminate the need for rest scans (11). Using similar low administered activities, multiple studies have shown D-SPECT imaging to have a high accuracy compared to invasive angiography (12,13). Overall, the ability to administer an overall lower activity not only reduces exposure to patients, but also to the technologist performing the studies.

D-SPECT Workflow

Preparation

Patient preparation for cardiac imaging with D-SPECT is the same as for conventional SPECT/CTs, including the need to refrain from caffeinated beverages and fasting for at least 4 hours. Limitations on other cardiac and systemic medications are not different from standard MPI protocols. Providing water after the rest injection can help minimize uptake in the liver, bowel, and gallbladder, as can longer delays between injection and imaging, and both are common methods for decreasing artifacts.

Positioning

The curved configuration of the D-SPECT allows for the heart to be imaged with the camera head at the closest possible position to the patient. When positioning for image acquisition, the patient may be either sitting upright (70°) or reclined supine (30°) with arms placed on the detector (Figure 1). The seat angle may be adjusted to any degree within the range, which can help compensate for subdiaphragmatic artifacts. Variations in body habitus are accommodated with the adjustable seat system. Once seated, the patient is positioned as far to the left as possible (slightly off center), all the while maintaining an erect and parallel position in the chair (no slouching if possible). Moving the chair is also necessary to position the heart in the FOV. The technologist, using the push button hand controller, manually aligns the camera head to closely fit up against the anterior chest and left lateral thoracic cavity (Figure 3). Overall, the ability to image patients in an upright position is more comfortable for patients compared to supine imaging on SPECT equipment.

Upright positioning is especially helpful when imaging patients with chronic obstructive pulmonary disease or dyspnea, as lying flat often exacerbates shortness of breath. The option of imaging upright can make the difference in completing a stress test exam (14). Frequently patient's arms are placed overhead on a conventional SPECT/CT, but using the D-SPECT requires only the left arm to be partially elevated. Regardless of the chair angle, the patient may choose to rest both arms directly upon the camera itself, or the right arm on the movable armrest.

Conventional SPECT imaging may require a patient to be placed in the prone position to minimize artifact. With D-SPECT, an alternative is to adjust the chair angle (Figure 1), which eliminates the discomfort associated with prone imaging (12), and these various positions can reduce artifact as mentioned previously (3,15). One study demonstrated the benefit of patient positioning with the D-SPECT in obese patients by comparing upright and supine views from the D-SPECT with a supine view from a conventional SPECT (11). Of the 101 patients on the SPECT camera, 74 needed a rest scan while only 42 of the patients scanned in an upright position on the D-SPECT required a rest scan. The study concluded that the addition of an upright image in obese patients improved the ability to determine if rest imaging was necessary, thus reducing the radiation exposure to the patients (11).

Detector Alignment

While imaging with the D-SPECT, the technologist aligns the heart blindly until the appropriate steps are taken on the acquisition computer during the pre-scan. Due to the D-SPECT's smaller FOV, localizing the heart can be difficult at first. Unlike conventional imaging using a live persistence-scope (p-scope), D-SPECT data is initially collected on the acquisition computer as a pre-scan. The alignment process takes a few seconds and aids in ensuring that the myocardium is centered within the FOV. This process may be repeated as many times as necessary in order to align the heart within three different regions of interest: anterior, lateral and axial (aerial). The technologist centers the heart all three planes displayed during the pre-scan to ensure the heart is centered within the FOV (16) (Figure 4).

This system of aligning the heart is unique to D-SPECT and may take some trial and error on behalf of the technologist. Initial alignment and pre-scan are especially important as processing with D-SPECT requires an accurate pre-scan, which is not needed on a conventional SPECT/CT or SPECT only systems. Time spent in pre-scanning results in time saved during post processing and limits the need for reimaging. Once the heart is located and region of interests (ROI) are drawn, image acquisition is set to begin.

Imaging

Once imaging is underway, neither patient nor camera moves. The only time the camera heads are moving is during the setup process, when the technologist manually moves the detector. This reduces the possibility of motion created artifacts or injuries. Lack of motion and noise, combined with the open seating configuration, decreases concerns of claustrophobia. The curved configuration of the D-SPECT, as it touches the patient just below the axilla, does not interfere with the patient's line of sight.

A D-SPECT acquisition, using technetium labeled perfusion agents, typically takes 2-8 minutes using standard As Low As Reasonably Achievable (ALARA) principle doses. Commonly used doses for the D-SPECT are shown in Table 2. Lower doses can be used, but would require longer imaging times. Rest and stress images are acquired with four lead electrocardiograms (ECGs) and multiple acquisitions in the upright and the supine position help to identify any breast or diaphragmatic attenuation artifacts. When using pharmacologic stress protocols while the patient is on the scanner, a separate 12 lead ECG may be required, as the camera is specifically designed to be used with 4 leads.

Postprocessing

The reconstruction algorithm on the D-SPECT is based on a maximum likelihood expectation maximization (MLEM) iterative reconstruction algorithm. This three dimensional MLEM implementation helps overcome the loss in spatial resolution caused by the larger collimator hole size (17). Multiple processing platform systems are available, similar to conventional SPECT systems. Processing accurately with D-SPECT is more contingent on the initial setup and the pre-scan than conventional processing systems. D-SPECT alignment is myocardial specific due to the smaller detectors and abridged FOV. Therefore, alignment requires a more precise centering of the heart (4). Drawing accurate left ventricle ROIs from the initial pre-scan, and at processing, is necessary for proper image quality controls and images (4) (Figure 5).

Room requirements

The D-SPECT has a considerably smaller footprint than conventional SPECT systems. Depending on the systems, the D-SPECT fits in a room as small as 9'5 x 11' (15). In actual practice, for comfort and safety, the room should be closer to 10' x 12' to allow for the dynamic imaging, injection of pharmacological agents and for additional personnel. This is still considerably less space than rooms for conventional nuclear medicine or SPECT/CT cameras which typically require rooms of 15' x 21' or larger.

Limitations

The main limitation of the D-SPECT system is the inability to perform attenuation correction. This can create challenges in the interpretation of some exams. Depending on body habitus, breast and diaphragmatic artifacts, these can limit the correct assessment of the anterolateral and inferolateral segments of the left ventricle. The possibility of acquiring images in different positions, helps overcomes this issue. These artifacts may hamper the use of a stress only imaging.

Subjects with large body habitus are also challenging for initial set up purposes. It is key to position the patient's heart in the FOV (displayed on the acquisition monitor) during the pre-scan step of the study. Despite this effort, there are some instances when the heart will not fit into the FOV, based on the excessive body tissue extending from the left side of the heart to the exterior left side of the patient that is in contact with the detector (Figure 6).

Although rarely a problem, patients with severe cardiomegaly pose issues to the imaging technologist due to the heart being larger than the FOV. During processing, portions of the myocardium could be cut out allowing for suboptimal diagnostic images of patients with cardiomegaly (18).

In a hospital setting, one of the larger drawbacks may be the D-SPECT's inability to handle immobile or less than cooperative patients. The chair position is not adequate for someone who is unable to sit upright on their own, one with involuntary movements or some patients with altered mental status.

Conclusion

D-SPECT technology has demonstrated to be a valid option to perform safe and accurate MPI studies, with benefits when compared to SPECT imaging. While CT attenuation technology, which is not available on the D-SPECT, increases the diagnostic value of conventional SPECT technology, the improved spatial resolution and sensitivity of the D-SPECT provides diagnostic myocardial perfusion imaging studies. The proximity of detector to patient improves image quality, while also reducing artifacts caused by patient movement. This close proximity also allows for reduced dose or imaging time both of which are beneficial to the patient and decreased exposure to the technologist. Arguably, the most advantageous detail of the patients' experiences with the D-SPECT camera is patient comfort due to the availability of upright positioning. Superior image quality, low dose and faster acquisition time, combined with optimal patient comfort demonstrate D-SPECT technology is advantageous to the patient, as well as to the nuclear medicine technologist acquiring the study.

Disclosures

No potential conflict of interest relevant to this article was reported.

Table 1: Comparison of the characteristics of sodium iodide (NaI) and cadmium zinc telluride (CZT) crystals used in detectors for cardiac SPECT and D-SPECT imaging systems (4).

Detector Crystal	Thickness (mm)	Energy Resolution (%)	Intrinsic Spatial Resolution (mm)	Count Rate (kcps)
NaI	9.5	10	4	≥250
CZT	5	6	2.5	≥600

Table 2: Example same day stress/rest or rest/stress (if needed) protocols with D-SPECT using a Tc99m based radiotracer. Doses are ranged based on weight and BMI. The top row shows the recommended dose from the ASNC guidelines, which are weight based and are in the range of 50% greater than the D-SPECT doses used in rows 2-4.

	Rest Study	**Stress Study**
Rest/Stress ASNC guidelines (4,9)	8-12 mCi (296-444 MBq) [conventional SPECT]	24-36 mCi (888-1332 MBq) [conventional SPECT]
Rest/Stress (12)	5.0 mCi (185 MBq) for < 91 kg 10.0 mCi (370 MBq) for >91 kg	12.5 mCi (463 MBq) for < 91 kg 25.0-30.0 mCi (925-1110 MBq) for >91 kg
Stress/Rest (10)	9.7 mCi (359 MBq) for 75 kg 22 mCi (814 MBq) for >110 kg	3.2 mCi (118 MBq) for 75 kg 7.0 mCi (259 MBq) for >110 kg
Stress/Rest (11)	17.5-31.0 mCi (648-1147 MBq) based on BMI	5.6-25.1 mCi (207-929 MBq) based on BMI

Figure 1: Patient positioning using the D-SPECT. Upright position on the D-SPECT demonstrates an approximate 70° chair angle with the detector at its closest proximity to the patient (A). The patient can rest both arms on top of the detector at about eye level or right arm may be placed on arm rest. Supine positioning on the D-SPECT at approximately 30° (B). Right arm may be placed on arm rest with left arm on top of the camera or positioned with the left on top of the camera or over patient's head. Multiple imaging positions can help to compensate for the lack of attenuation correction. Using a conventional SPECT camera with the patient in a supine position; both detectors at 90° with arms over head (C).

Figure 2: Example case demonstrating the presence of inferior wall attenuation artifact seen occasionally on D-SPECT images (top set of images). In the distal inferior wall, decreased uptake is shown in the (white arrows) on both rest and stress images. Note the sharper delineation of the myocardium with the D-SPECT compared to those acquired on the SPECT/CT (middle and lower images).

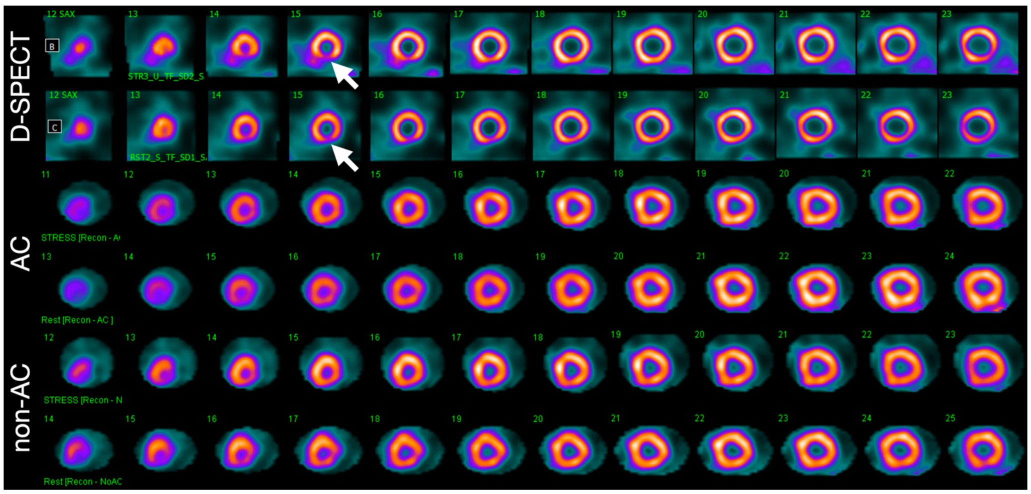


Figure 3: Aerial view of camera heads arranged inside of the gantry, showing approximate angles taken to achieve the images. Red lines indicate the heart centric FOV of one of the nine detectors.

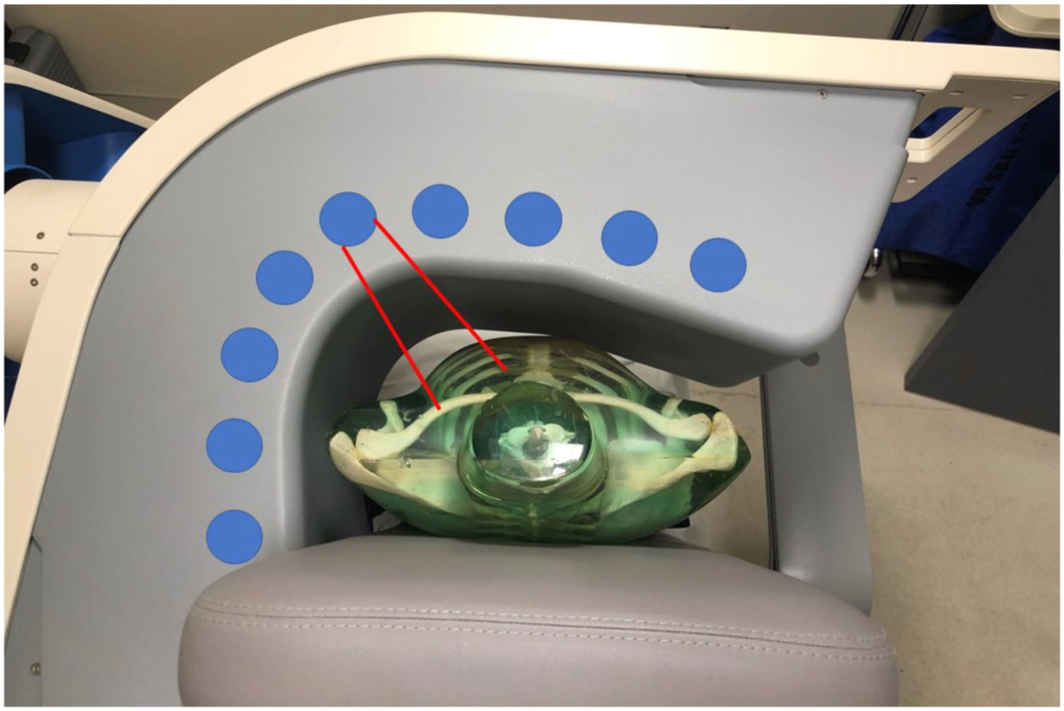


Figure 4: A pre-scan is to ensure the heart is accurately centered within the FOV. "Front" and "Side View" arrows indicate the superior and inferior limits. The "Top View" arrow points to the white dotted circle which is the D-SPECT indicator for lateral left side heart alignment. For appropriate imaging, the heart must touch the white dotted circle, at a minimum. The red circle needs to be adjusted to fit around the myocardium, on all three views for optimum count statistics.

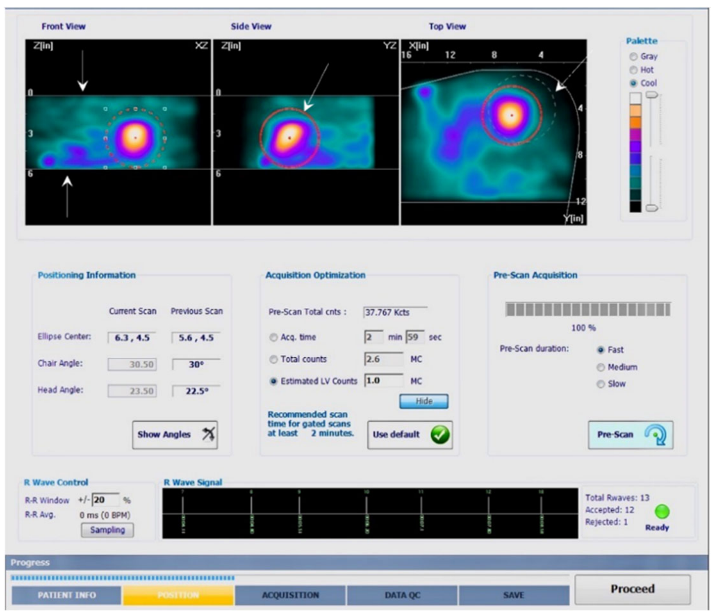


Figure 5: D-SPECT Post Scan View. If pre-scan centering was accurate, each of the 9 camera FOV's will be centered as in this image. The two separate vertical columns, left and right, represent the first and the second sweep of the detector. The nine detectors scan based on the ROI drawn by the technologist and then all the detectors shift on a linear motor and scan again. Then these 2 sweeps are zipped together. The vertical lines are the "positions" or stops (equal to stops on a traditional scanner) of which there are 60 for each detector per scan. A dark space appears above and below which indicates accurate pre-scan FOV alignment.

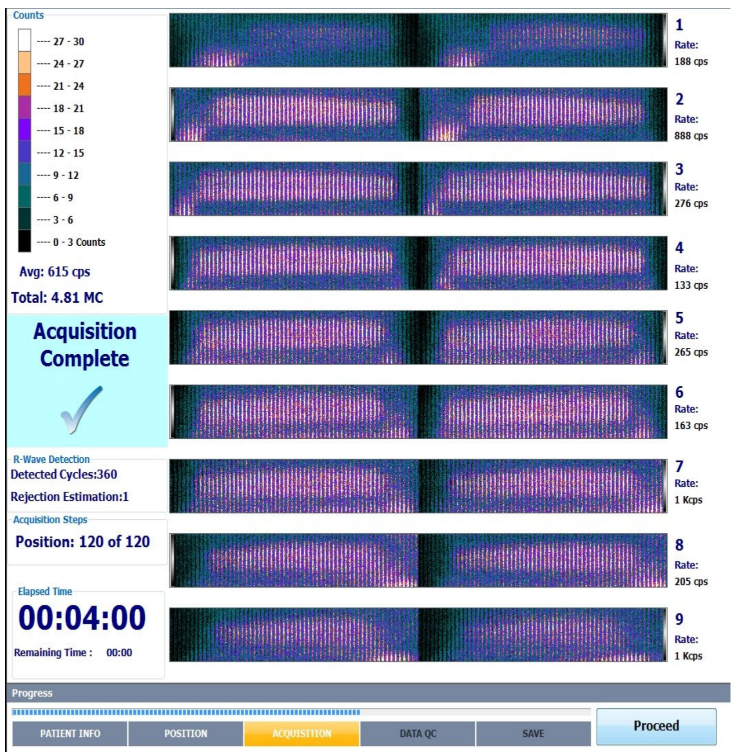
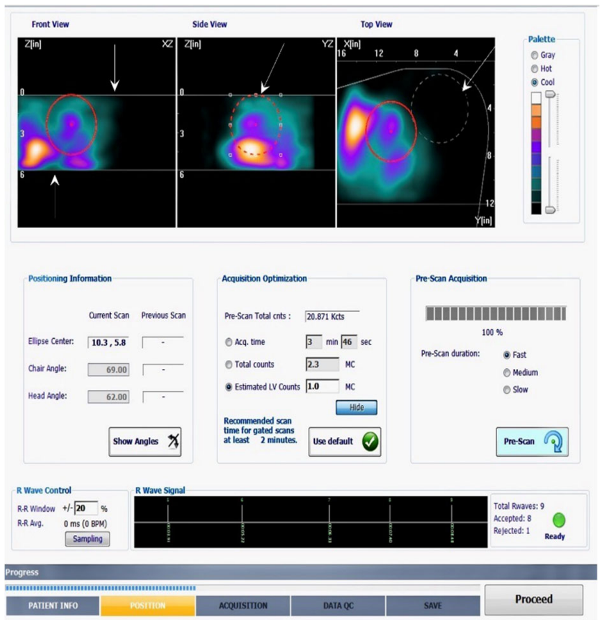


Figure 6: Example of poor positioning on the D-SPECT pre-scan interface. Though “Frontal” and “Side View” are aligned within the superior and inferior limits (white arrows), the “Top View” target area (white dotted circle) shows the heart is outside of the FOV. This can occur with obese patients or when the patient and/or camera is not adequately lined up to the left.



References

1. Benjamin EJ, Muntner P, Alonso A, et al. Heart Disease and Stroke Statistics-2019 Update: A Report From the American Heart Association. Circulation. 2008 ed. 2019;139:e56–e528.

2. Beller GA, Zaret BL. Contributions of nuclear cardiology to diagnosis and prognosis of patients with coronary artery disease. Circulation. 2000;101:1465–1478.

3. Agostini D, Marie P-Y, Ben-Haim S, et al. Performance of cardiac cadmium-zinc-telluride gamma camera imaging in coronary artery disease: a review from the cardiovascular committee of the European Association of Nuclear Medicine (EANM). Eur J Nucl Med Mol Imaging. 2016;43:2423–2432.

4. Dorbala S, Ananthasubramaniam K, Armstrong IS, et al. Single Photon Emission Computed Tomography (SPECT) Myocardial Perfusion Imaging Guidelines: Instrumentation, Acquisition, Processing, and Interpretation. J Nucl Cardiol. 3rd ed. 2018;25:1784–1846.

5. Erlandsson K, Kacperski K, van Gramberg D, Hutton BF. Performance evaluation of D-SPECT: a novel SPECT system for nuclear cardiology. Phys Med Biol. 2009;54:2635–2649.

6. Gambhir SS, Berman DS, Ziffer J, et al. A novel high-sensitivity rapid-acquisition single-photon cardiac imaging camera. Journal of Nuclear Medicine. Society of Nuclear Medicine. 2009;50:635–643.

7. Alexiev D, Mo L, Prokopovich D, Smith ML, Matuchova M. Comparison of LaBr3 : Ce and LaCl3 : Ce and With NaI(Tl) and Cadmium Zinc Telluride (CZT) Detectors. IEEE Transactions on Nuclear Science. 2008;55.

8. Burrell S, MacDonald A. Artifacts and pitfalls in myocardial perfusion imaging. J Nucl Med Technol. 2006;34:193–211–quiz212–4.

9. Henzlova MJ, Duvall WL, Einstein AJ, Travin MI, Verberne HJ. ASNC imaging guidelines for SPECT nuclear cardiology procedures: Stress, protocols, and tracers. J Nucl Cardiol. 2016;23:606–639.

10. Perrin M, Djaballah W, Moulin F, et al. Stress-first protocol for myocardial perfusion SPECT imaging with semiconductor cameras: high diagnostic performances with significant reduction in patient radiation doses. Eur J Nucl Med Mol Imaging. 2015;42:1004–1011.

11. Ben-Haim S, Almukhailed O, Neill J, et al. Clinical value of supine and upright myocardial perfusion imaging in obese patients using the D-SPECT camera. J Nucl Cardiol. 2014;21:478–485.

12. Duvall WL, Sweeny JM, Croft LB, et al. Comparison of high efficiency CZT SPECT MPI to coronary angiography. J Nucl Cardiol. 2011;18:595–604.

13. Duvall WL, Sweeny JM, Croft LB, Ginsberg E, Guma KA, Henzlova MJ. Reduced stress dose with rapid acquisition CZT SPECT MPI in a non-obese clinical population: comparison to coronary angiography. J Nucl Cardiol. Springer-Verlag. 2012;19:19–27.

14. Botvinick EH, Zhu YY, O'Connell WJ, Dae MW. A quantitative assessment of patient motion and its effect on myocardial perfusion SPECT images. Journal of Nuclear Medicine. 1993;34:303–310.

15. Case JA, Bateman TM. Taking the perfect nuclear image: Quality control, acquisition, and processing techniques for cardiac SPECT, PET, and hybrid imaging. J Nucl Cardiol. 2013;20:891–907.

16. Allie R, Hutton BF, Prvulovich E, Bomanji J, Michopoulou S, Ben-Haim S. Pitfalls and artifacts using the D-SPECT dedicated cardiac camera. J Nucl Cardiol. Springer US. 2016;23:301–310.

17. Agostini D, Marie P-Y, Ben-Haim S, et al. Performance of cardiac cadmium-zinc-telluride gamma camera imaging in coronary artery disease: a review from the cardiovascular committee of the European Association of Nuclear Medicine (EANM). Eur J Nucl Med Mol Imaging. Springer Berlin Heidelberg. 2016;43:2423–2432.

18. Rosenthal MS, Cullom J, Hawkins W, Moore SC, Tsui BM, Yester M. Quantitative SPECT imaging: a review and recommendations by the Focus Committee of the Society of Nuclear Medicine Computer and Instrumentation Council. Journal of Nuclear Medicine. 1995;36:1489–1513.