

Pitfalls and Artifacts Using the D-SPECT Dedicated Cardiac Camera

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Abstract

Myocardial perfusion imaging (MPI) is a well-established and widely used imaging technique for the assessment of patients with known or suspected coronary artery disease. Pitfalls and artifacts associated with conventional gamma cameras are well known and the ways to avoid and correct them have been described. In recent years solid-state detector dedicated cardiac cameras were introduced and have been shown to offer improved accuracy in addition to new imaging protocols and novel applications. The purpose of this manuscript is to familiarize the readers with the causes and effects of technical, patient related and operator-related pitfalls and artifacts associated with the D-SPECT dedicated cardiac camera with solid-state detectors. The manuscript offers guidance on how to avoid these factors, how to detect them and how to correct better for them, providing high-quality diagnostic images.

Abbreviations list

MPI- myocardial perfusion imaging

CAD- coronary artery disease

CZT- Cadmium Zinc telluride

LEHR- Low energy high resolution

QC- quality control

ROI-region of interest

LV-left ventricle

RFID-radiofrequency identification

Introduction

Myocardial perfusion imaging (MPI) is a well-established imaging technique in patients with known or suspected coronary artery disease (CAD) and is used extensively for diagnosis, assessment of response to therapy and risk stratification. Pitfalls and artifacts have been described with conventional MPI SPECT and may degrade image quality leading to misinterpretation of studies (1).

In recent years novel dedicated cardiac cameras with solid state Cadmium Zinc Telluride (CZT) detectors have been introduced (2, 3). The CZT technology with new hardware, new imaging acquisition techniques, ultrafast scan times and sophisticated software innovations, enables advanced applications, such as low dose MPI, simultaneous dual-radionuclide imaging and dynamic SPECT (4-9).

In this manuscript we review technical, patient-related and operator-dependent pitfalls and artifacts specific to the D-SPECT camera, aiming to raise the awareness of these factors and the need to limit them whenever possible.

BACKGROUND

The D-SPECT camera

The design of the D-SPECT camera has been previously described (8). Briefly, the camera consists of 9 pixelated detector columns, arranged in a curved configuration that encloses the left side of the patient's chest. The camera is equipped with Tungsten parallel-hole collimators that are shorter and have larger square holes compared to standard lead parallel-hole LEHR collimators, resulting in more than 8 times improved sensitivity. Behind each collimator column there is an array of 2.46 x 2.46 mm, 5mm thick CZT crystals (16 x 64 pixels, 40mm x 160mm) (Fig. 1).

Daily QC

Quality control is performed on a daily basis with a Cobalt rod source. The source is positioned in a dedicated arm that attaches to the machine. The QC procedure takes 2 minutes with a new source and longer as the source gets older.

Figure 2a shows an example of a normal daily QC report

A traffic light system is used to indicate the status of the camera, where green indicates all parameters are within specification, red indicates not to use (Figure 2b) and orange indicates to apply caution as one or more parameters may be nearing acceptance threshold.

Acquisition

Each detector column rotates along its long axis up to 110° independently, focusing on a pre-specified region of interest (ROI) that includes the heart. A pre-scan of 30-60 sec is performed prior to the acquisition to define the ROI. During acquisition more

time is allocated to collect data from this specific ROI, while fewer data are collected from other regions in the field of view (Figure 3). The data are acquired in list mode and physiologic markers, such as the R wave of the ECG, are recorded for gating.

The D-SPECT camera demonstrates 8 to 10 times improvement in sensitivity compared to conventional systems, due to the combined wide-angle collimator and region-centric acquisition, as well as improved reconstructed resolution and superior energy resolution (10).

Images can be obtained for a fixed pre-defined time, or by acquiring a pre-defined amount of counts from the LV. Recently it has been proposed that 1M LV counts provide adequate imaging and allow for adequate quantitative analysis (6).

At the end of acquisition a sinogram is displayed as part of the QA process (Figure 4). In addition, the counts from all detectors in each position are summed. Two sweeps of the detectors are normally obtained with detectors slightly rotated to complete 180° acquisition, creating a panogram and enabling motion detection (Figure 4).

Imaging can be performed supine or semi-upright (Figure 1). The camera has a built-in inclinometer to indicate the angle of the couch and of the detector head during each scan, enabling replication of images in exactly the same position. Exact alignment of the angle is needed to avoid mis-alignment of stress and rest data sets.

The arm rest has a built-in radiofrequency chip which can be set up to read information off a patient wristband, ensuring patient identification is correct for every patient with each scan. Patient data can also be automatically downloaded from radiological/ patient information systems.

Image Reconstruction

Reconstruction is performed in 2 steps. In the first step with 3 iterations, the LV region and orientation are determined and LV counts are calculated. Four further iterations are subsequently performed (6). The reconstruction algorithm is based on the maximum-likelihood expectation maximization method with resolution recovery, 4-7 iterations and 32 subsets and additional kernel convolution smoothing, creating transaxial images (8). A Gaussian post-reconstruction filter as well as a proprietary normalizing post-reconstruction filter are used. No attenuation correction and no scatter correction are applied. Transaxial images are automatically reoriented into short-axis and vertical and horizontal long-axis slices using the quantitative perfusion SPECT software (QPS, Cedars-Sinai Medical Center).

PITFALLS AND ARTIFACTS

Artifacts can be divided into 3 categories: mechanical, patient-related and operator-induced.

Mechanical Faults

These are faults that occur due to failure of the system's hardware or software.

“Noisy” Module

Electronic noise may be inherently present within a detector module and may affect uniformity (Figure 2). During acquisition this appears as a band of reduced but not absent uptake (Figure 5). On the panogram and raw data QC it can appear as an area of increased intensity (Figure 5). A noisy module may have no effect on the perfusion datasets or it may mimic reduced myocardial perfusion warranting a repeat scan, depending on the location of the affected module (Figure 5).

The software detects noisy pixels and alerts throughout the scan. In most cases, recalibration of the system followed by daily QC will fix the problem. If the problem persists, the noisy module should be replaced.

“Absent” Module

In this case either the hardware component has failed or there is an interruption in the power supply to the specific module. Due to the disruption in electronic signal, no counts will be detected in the affected module. This area will appear as a blacked out area in the scan QC and a jagged broken line on the sinogram (Figure 5).

Depending on the specific location relative to the LV, it may or may not have an effect on the perfusion data. It is necessary to replace the failed module as soon as possible, followed by system recalibration.

Patient-related Artifacts

Motion

Patient motion is common and one of the most important sources of artifact on MPI (11), also creating artifacts on D-SPECT MPI. It is possible, however, since scanning time is much shorter on D-SPECT, motion will be encountered less frequently.

Motion caused by breathing is usually not a source of artifacts, whereas gross motion or coughing with motion may create artifacts. Vertical or horizontal motion can be easily detected on the panogram of the scan QC (Figure 6).

The technologist should ensure the patient is comfortable before the start of acquisition to limit the possibility of motion.

Currently there is no motion correction on the D-SPECT, however, scans are relatively short (2-6 minutes, depending on injected activity) and repeat scanning is recommended where the severity and frequency of the motion impacts on the quality of perfusion data.

Attenuation

Attenuation is one of the most prevalent sources of artifacts on conventional MPI and may reduce the accuracy of MPI. Although image quality is generally preserved on D-SPECT also in obese patients, attenuation artifacts may occur, including breast attenuation in women with large breasts and diaphragmatic attenuation in obese men.

Attenuation correction is not currently available on D-SPECT. A CT scan can be performed on another camera and the data can be used for attenuation correction (12). Supine and upright imaging may be performed which can assist in the differentiation between soft tissue attenuation artifacts and real perfusion defects (13), (Figure 7, Figure 8). Prone imaging, known to improve the accuracy of conventional MPI, is also feasible with D-SPECT (14). In addition, in the case of a fixed defect gated stress/rest MPI can be used to characterize these defects as infarct or attenuation artifact, similar to gated MPI performed on a conventional camera (15). It should be noted, however, that while function will help, a non-transmural infarct can be associated with a fixed defect and a normal LV function.

Extra-cardiac uptake

Extra cardiac activity is most often due to sub-diaphragmatic liver and gut uptake adjacent to the heart. This can create artifacts, similar to conventional MPI, mainly interfering with the evaluation of the inferior wall. Scatter and volume averaging may

cause apparent increased inferior wall uptake, but artifactual reduced activity in the inferior wall can also occur. Images can be repeated in a different position and acquired both in supine and in upright postures, helping in the assessment of all myocardial regions and the identification of artifacts (Figure 9, Figure 10). The scan can also be repeated at a later time point, and it has been suggested that drinking of cold water or soda water may accelerate washout of gut uptake.

Infero-apical artifact

Reduced uptake has been observed in the infero-apical region, more commonly seen on upright scans, and this may mimic a perfusion defect (Figure 7). The mechanism by which this artefact is produced is not entirely understood, possible explanations include: abrupt motion or heavy breathing, affecting mainly the apical area that is perpendicular to the motion, extra-cardiac uptake in proximity to the LV apex, soft tissue attenuation caused by large breasts or diaphragm, or partial volume effect due to apical thinning.

Motion, attenuation and extra-cardiac activity artifacts have been discussed. It is recommended to check the scan and the scan QC thoroughly for these artifacts and to repeat the scan at a later time point or a different position if likely artifactual tracer distribution is observed. In addition it is recommended to assess myocardial perfusion at the end systolic (ES) phase on the gated data. In ES the LV contracts resulting in a better separation from the diaphragm, therefore if an artifact is present it will not persist at the same location of the myocardium. Although all of these occur also with conventional MPI, the artefact is more prominent on D-SPECT images, perhaps due to the improved resolution of these images.

Operator-Induced artifacts

Extravasation/Tissued injection

Extravasation of the radiopharmaceutical can lead to suboptimal imaging as there may not be sufficient counts to demonstrate uptake in the myocardium. The extravasated tracer may cause count saturation, resulting in less count statistics from the area of interest. It is preferable to elevate the arm with the extravasated tracer so that it is not included in the field of view. In addition, acquiring in LV mode (i.e. pre-setting LV counts) is advisable as opposed to time-based acquisition, to ensure there are enough counts acquired from the LV. If rest/stress imaging is performed LV counts and count rate can also help to identify the rare case of a full extravasation of the stress dose.

Wrong Scan Pattern

It is important to select the correct ROI from the pre-scan, centered on the LV. This may be challenging in patients with high gut uptake adjacent to the LV, or patients who do not mobilise well. The gut may mimic the shape of the left ventricle on the pre-scan and therefore it is important to check the images in all 3 planes during processing (Figure 11)

Incorrect Contours

Processing of the data should be consistent. The automatic contouring will work in most cases, however, it is important to always check the gated data and assess that the contours follow the motion of the heart muscle throughout the cardiac cycle.

Problems with contouring occur when there is extracardiac activity in close proximity to the heart, e.g. gut uptake, hiatus hernia.

Incorrect contours can be corrected manually by adjusting the ROI over the myocardium and masking out the gut activity. In some cases the ‘constrict’ function should be applied to limit the ROI from incorporating gut activity (Figure 10).

Acquiring under wrong radiotracer or wrong energy window

On D-SPECT the collimator does not need to be changed when switching from one radiotracer to another. In addition, when the wristband is used the radio-frequency identification (RFID) on the imaging couch detects the patient details, study type and tracer dose which are displayed on the acquisition monitor and should be checked by the operator.

It is, however, possible to make an error if the operator erroneously enters incorrect scan or patient details. It should be immediately apparent during scanning as non-uniform images.

Wrong Filter

When the wrong filter is used for processing image quality may be affected. This may also have an impact on the resolution and the contrast of the images and in rare cases may also affect study interpretation.

Other Causes of Artifacts

In this section we address potential artifacts which may be associated with specific imaging protocols developed for the dedicated cardiac camera with solid state detectors, namely simultaneous dual-radionuclide imaging (16) and dynamic myocardial perfusion SPECT (17).

Simultaneous dual-tracer stress-rest myocardial perfusion imaging may have the advantage of the simultaneous acquisition, with exact alignment between the stress and rest data, eliminating positional changes and with similar effects of motion artifacts and gut activity on both sets of images (16). While dual-imaging with Tl-201 and Tc-99m is done less frequently, this method can be used for the simultaneous assessment of myocardial perfusion and innervation (13). Artifacts may occur due to spillover between the energy windows. Approaches providing the methods of correction of spillover artifacts specific to cameras with CZT detectors were published (18, 19).

The high sensitivity, fast angular sampling and ROI-focused imaging capability of the D-SPECT camera enables dynamic cardiac SPECT. Dynamic cardiac SPECT. This can provide absolute quantitative indices of myocardial perfusion, potentially improving the accuracy of the test (17). The suggested protocol involves fast acquisition during which the detectors acquire for periods following injection of the tracer that can be shorter than the respiratory cycle. The acquisition frame rate must be sufficiently fast to capture the kinetics but artifacts and reduced image quality can result when the angular dwell time is lower than the respiratory period (D. Salvado, MSc thesis, Univ of Lisbon 2012). This potential source of artifacts deserves further investigation.

Conclusion

We have described pitfalls and artifacts that may occur with the D-SPECT camera due to mechanical faults, patient-related or operator-induced artifacts. It is essential for the technologist and the interpreting physician to recognise these potential sources of

errors in order to avoid misinterpretation and to limit them as much as possible in order to improve image quality and the clinical performance of MPI.

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REFERENCES

- 1) Burrell S., MacDonald A. Artifacts and pitfalls in myocardial perfusion imaging. *J Nucl Med Technol* 2006; 34:193-211.
- 2) Garcia EV, Faber T.L., Esteves F.P. Cardiac dedicated ultrafast SPECT cameras: new designs and clinical implications. *J Nucl Med* 2011; 52:210-217.
- 3) Imbert L., Poussier S., Franken P.R., et al. Compared performance of high-sensitivity cameras dedicated to myocardial perfusion SPECT: a comprehensive analysis of phantom and human images. *J Nucl Med* 2012; 53:1-7.
- 4) Ben-Haim S., Kacperski K., Hain S., et al. Simultaneous dual-radionuclide myocardial perfusion imaging with a solid-state dedicated cardiac camera. *Eur J Nucl Med Mol Imaging* 2010; 37(9):1710-21.
- 5) Ben-Haim S., Murthy V.L., Breault C., et al. Quantification of myocardial perfusion reserve using dynamic SPECT imaging in humans: a feasibility study. *J Nucl Med* 2013;54:873-79.
- 6) Nakazato N., Berman D.S., Hayes S.W., et al. Myocardial perfusion imaging with a solid-state camera: simulation of a very low dose imaging protocol. *J Nucl med* 2013; 54:1-7.
- 7) Gimelli A., Bottai M., Genovesi D., Giorgetti A., Di Martino F., Marzullo P. High diagnostic accuracy of low-dose gated SPECT with solid-state ultrafast detectors: preliminary clinical results. *Eur J Nucl Med Mol Imaging* 2012;39:83-90.

- 8) Gambhir S.S., Berman D.S., Ziffer J., et al. A novel high-sensitivity rapid acquisition single-photon cardiac imaging camera. *J Nucl Med* 2009;50:635-643.
- 9) Slomka P.J., Berman D.S., Germano G. New cardiac cameras: Single-photon emission CT and PET. *Semin Nucl Me* 2014;44(4):232-251.
- 10) Erlandsson K., Kacperski K., van Gramberd D., Hutton B.F. Performance evaluation of D-SPECT: a novel SPECT system for nuclear cardiology. *Phys Med Biol* 2009; 54:2635-2649.
- 11) Wheat J.M., Currie G.M. Impact of patient motion on myocardial perfusion SPECT diagnostic integrity: Part 2. *J Nucl Med Technol* 2004; 32:158-163.
- 12) Ernst S., Menichetti F., Roth N., et al. Image integration of dual radio-nuclide imaging of perfusion and sympathetic activity with 3D computer tomography for ventricular arrhythmia management – an initial experience. *Heart Rhythm*, 2014; 11(May Supplement), S462
- 13) 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.
- 14) 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.
- 15) DePuey E.G., Rozanski A. Using gated Technetium-99m-Sestamibi SPECT to characterize fixed myocardial defects as infarct or artefact. *J Nucl Med* 1995;36:952-955.

- 16) Ben-Haim S, Kacperski K, Hain S, et al. Simultaneous dual-radionuclide myocardial perfusion imaging with a solid-state dedicated cardiac camera. Eur J Nucl Med Mol Imaging. 2010;37(9):1710-21.
- 17) Ben-Haim S., Murthy V.L., Breault C., et al. Quantification of myocardial perfusion reserve using dynamic SPECT imaging in humans: a feasibility study. J Nucl Med 2013; 54:873-879.
- 18) Kacperski K, Erlandsson K, Ben-Haim S, Hutton BF. Iterative deconvolution of simultaneous ^{99m}Tc and ^{201}Tl projection data measured on a CdZnTe-based cardiac SPECT scanner. Phys Med Biol. 2011; 56(5):1397-414.
- 19) Holstensson M., Erlandsson K., Poludinowski G. et al, Model-based correction for scatter and tailing effects in Simultaneous ^{99m}Tc and ^{123}I imaging for a CdZnTe cardiac SPECT camera. Phys Med Biol. 2015; 60(8): 3045-63.

LEGENDS FOR FIGURES

Figure 1: The D-SPECT camera and acquisition station. Left: In the camera head there are 9 detector columns, swiveling during acquisition 110 degrees about their long axis, focusing on the heart. Right: A detector column. Each detector column is composed of 4 detector modules, 16x16 CZT elements, measuring 2.46 x2.46 mm and 5mm thick. There are 1024 CZT elements/column.

Figure 2: (a) Normal QC report: uniform uptake in all detectors (center), normal energy resolution (bottom left). During acquisition the registration of the rod source should fall within the limits (10% window, bottom right). Bottom Center: This is a sinogram of the line source and should be straight, indicating no movement in between projections. Traffic light system indicates the status of the camera (top right), green indicates all parameters are within specification. (b) “Noisy” detector due to electrical noise causing inhomogeneity in detector no. 4 (center). The QC screen is abnormal with a red light, indicating the camera is not suitable for use.

Figure 3: Scan Acquisition. (a) 30 sec pre-scan is performed to determine a region of interest that includes the heart (b); Bottom: Focused scan is performed, centered on the heart (c) with illustration of reconstructed data (d).

Figure 4: Post-scan QC. Top: Sinogram (left), raw cine data (center) and panogram sweeps 1&2 (right). Bottom: gating QC with indication of accepted and rejected beats.

Figure 5: Hardware artifacts. (a) Sinogram showing “absent” (failed) detector. (b) “Absent” half module in the detector column (top right), on the post-scan QC screen (top left), appears as a band of absent activity on the raw data cine images (bottom

right). Due to the location of the failed module it has not affected the MPI appearances (bottom left). (c) “Noisy” module: As seen on the QC report (bottom left) and sinogram (top left). Artifact is seen on the panogram (top right) and raw data cine display (middle right). In this case due to the location this has affected the scan appearances (bottom right).

Figure 6: Motion artifact. (a) Panogram showing breathing artifact during stress (top right). (b) Severe motion artifact at rest seen on the sinogram (bottom left) and panogram (top right), causing distortion of MPI (c).

Figure 7: Breast attenuation artifact. (a) Different appearances on supine and upright MPI and different attenuation patterns on the corresponding supine (b) and upright (c) sinograms and raw cine data due to change in location of the breast (red arrow). In addition, infero-apical artifact seen on upright imaging, but not on supine (yellow arrow).

Up=upright; Sup=supine

Figure 8: Diaphragmatic attenuation artifact. Severely reduced basal inferior wall uptake on the supine acquisition, showing improvement on the upright study (yellow arrow).

Sup=supine; Up=upright

Figure 9: Extra cardiac activity. (a) Supine stress images show “hot” gut adjacent to and obscuring the inferolateral region. (b) Changing position to semi-upright the gut activity is no longer interfering with MPI images.

STR=stress; RST=rest

Figure 10: Extra cardiac activity. Automatic contours (a) and manually adjusted contours (b) for perfusion (top) and gated (bottom) data sets in a patient with gut activity adjacent to the LV

Figure 11: Incorrect ROI selection. (a) Choice of wrong ROI on the 30sec pre-scan results in deformity of the LV on MPI (b)