“Picture-in-Picture” Artifact: Introduction and Characterization of a Hitherto Unrecognized Imaging Artifact in Creating Perfusion Defects in Myocardial Perfusion Single-Photon Emission Computed Tomography

Abstract
Following a moving hot spot in the projections of raw images and profound perfusion defects in myocardial perfusion single-photon emission computed tomography (SPECT) imaging of a patient, a hypothesis was postulated that the perfusion defects were artifactual, and the high activity concentration of the gallbladder may be a culprit for this phenomenon, owing to flawed event positioning function of the gamma camera due to a malfunctioning digital event processor electronics board. To depict the characteristics of this artifact, a point source containing an activity of 3 mCi of pertechnetate is placed on the scanning table with the detector facing the table (at a distance of 30 cm), and then, in other detector positions and 1-min static images are acquired accordingly. The ratio is calculated as follows: count of the artificial focus: 1860, count of the index focus: 705,727, and artifactual-to-index focus ratio: 0.003. In testing the uniformity of gamma camera based on the National Electrical Manufacturers Association protocol, a nonuniform response was detected, seemingly, a smaller field of view (FOV) is reproduced in the main FOV causing nonuniformity more than the acceptable level. The smaller flood image lies in the upper right corner of the main flood image. In essence, the extremely bright gallbladder was the source of error, and its image was reproduced in the FOV, which was superimposed on the left ventricular myocardium in some of the projections and was propagated to SPECT images.

Keywords: Gamma camera, imaging artifact, myocardial perfusion single-photon emission computed tomography, perfusion defects, picture-in-picture artifact

Introduction
Artifacts as an undesirable aspect of medical imaging could impact the visual interpretation and quantitation of clinical images. A diverse range of artifacts has been introduced in nuclear medicine images, which can be categorized according to its source. Specifically, in nuclear cardiology images, artifacts may result from special features or conditions of patients being imaged or, more importantly, from an error or fault in the instrumentation or in the algorithms of image formation, reconstruction, and display. Characteristics and the mechanism by which the artifact arises as well as the extent to which the final image is influenced may be of interest to nuclear cardiology practitioners. However, daily routine quality control procedures of the hardware and checking the software of imaging systems are assumed as safeguards against unintentional misinterpretation. [1-3]

In this article, a new artifact is introduced and is characterized during myocardial perfusion single-photon emission computed tomography (SPECT) imaging using a gamma camera. The impact of such artifact in SPECT images and its potential for misdiagnosis is also depicted.

Methods and Findings
Patient study
A 48-year-old male was referred for a 1-day exercise stress-rest myocardial perfusion SPECT with ⁹⁹ᵐTc-Methoxy isobutyl isonitrile because of atypical chest pain developed over the past few weeks. The patient had no other cardiovascular risk factors. SPECT imaging was obtained using a single-headed Genesys ADAC gamma camera. There was a recent provisional replacement of a faulty electronic hardware item (digital...
event processor [DEP] electronics board) of the gamma camera in our department with another one, which had also a minor malfunction (minor error in event positioning function). Imaging protocol and acquisition and processing parameters were set as routine. The stress image was unremarkable (not shown), but the rest image [Figure 1] demonstrated some deformation of the left ventricular (LV) and notable nonuniform distribution of the radiopharmaceutical in the myocardium. The septum and basal lateral wall showed bright foci, and as a consequence, the remainder of the LV myocardium was downscaled. Inspection of cinematic raw images revealed a focal hot spot in the LV myocardium moving from the lateral wall to the septum, which was absent in the stress image. Interestingly, the hot spot was absent or less bright in projections with less activity accumulated in the gallbladder, and there was a constant distance between the spot and gallbladder. We thought that this might have resulted from the mentioned hardware error, therefore, the rest image was repeated 1 h later, after the ingestion of a fatty meal [Figure 2]. This time, no corresponding hot spot was observed in the LV myocardium or around the heart on cinematic raw images. The SPECT images also showed a fairly uniform $^{99m}$Tc-MIBI distribution.

**Imaging of point source**

To depict the characteristics of this artifact, a point source containing an activity of 3 mCi of pertechnetate is placed on the scanning table with the detector facing the table (at a distance of 30 cm), and then, in other detector positions and 1-min static images are acquired accordingly (Collimator: low-energy/high-energy resolution, matrix size: $128 \times 128$) [Figure 3a and c]. The count of each focus is derived by drawing a region of interest around each on the obtained images, and then, the ratio is calculated as follows: the count of the artifactual focus: 1860, the count of the index focus: 705,727, and the artifactual-to-index focus ratio: 0.003. The count profile is also drawn [Figure 3d]. The peak of the artifactual spot is barely visible with respect to the peak of the main spot. The location of the peak of the artifactual spot is marked by an arrow [Figure 3d]. Then, to examine the geometrical properties of this artifact, three points with roughly equal activity are placed on the scanning table in a triangular-shaped arrangement, as it is shown in Figure 3f. The respective places of the artifactual and index images were the same as that of the point source, and no horizontal or vertical flipping or other forms of change in the orientation were observed [Figure 3b, Figure 3e].

**Uniformity testing**

For testing the uniformity of gamma camera detector response to the radiation across the field of view (FOV), a point source of 500 $\mu$Ci pertechnetate ($^{99m}$Tc) was placed at a distance of about 2 m away perpendicular to the surface of the detector after removing the collimator based on the National Electrical Manufacturers Association protocol. The acquisition parameters for the flood image were matrix size of $256 \times 256$, pixel depth of 16 bits. The matrix is adjusted to obtain a pixel size of 1.56 mm in a gamma camera with a $40 \text{ cm} \times 53\text{ cm}$ FOV. The energy window is centered over the 140 keV with a width of 20% of the $^{99m}$Tc photpeak. Count collection is continued until a total count of 15 million is acquired. Before proceeding to derive quantitative indices of uniformity, the flood image is smoothed with a 9-point kernel. The flood image is analyzed visually, and

---

Figure 1: Cinematic raw images (32 projections from the left posterior oblique to the right anterior oblique) (a) and corresponding single-photon emission computed tomography image (b) of the initial rest image. A bright hotspot (indicated by arrows) is visible in the lateral wall of the left ventricular myocardium roughly from projection 17–21. Then, over later projections, the hotspot moves gradually to eventually reside in the septal wall (projections 25–32). Single-photon emission computed tomography image shows some deformation of the left ventricular with the downsampling artifact as a result of the intense foci of uptake in the septum, more noticeably, and also basal lateral wall.

Figure 2: Cinematic raw image (32 projections from the left posterior oblique to the right anterior oblique) (a) and corresponding single-photon emission computed tomography image (b) of the repeat rest image with the same acquisition and processing parameters after ingestion of a fatty meal to empty gallbladder. No hotspot is observed in the left ventricular myocardium or around the heart in raw images, and no perfusion defect is seen in single-photon emission computed tomography image.
then, quantitative indices of uniformity including integral and differential uniformity (DU) are derived for useful FOV and central FOV. For integral uniformity, the pixels with maximum and minimum counts in the whole flood image are found, and then, the subtraction of maximum and minimum counts per pixel is divided by the addition of maximum and minimum counts per pixel.

Similarly, for DU, the pixels with the highest and lowest counts are found in sets of 5 pixels in rows or columns across the image matrix, then, the maximum value is acquired. The results were expressed in percentages. As can be seen in Figure 4a, a nonuniform response is detected, seemingly, a smaller FOV is reproduced in the main FOV causing nonuniformity more than the acceptable level. The smaller flood image lies in the upper right corner of the main flood image. Afterward, the mentioned hardware is replaced with a properly functioning one, and again, the uniformity tests are acquired [Figure 4b]. This time, acceptable results were obtained.

**Discussion**

To date, varieties of artifacts have been introduced in nuclear medicine images. Some of those affect the clinical images, and in extreme cases may cause a misleading effect on the interpretation. The artifact introduced in this article is one of such examples. As it is evident in Figure 1, the clinical impact of this error could be profound. As it is shown in Figure 3, the orientation of the artifact is not related to the gantry or detector position. In each position, the image is depicted in the upper right corner of the main image. This constant relative standing is worthy of note for clinicians and technicians involved in such situation that helps recognize the artifact from the real hot lesions. Since the count ratio is remarkably low, this artifact seems to be visible only in images with a very intense hot spot against the very low activity background, similar to those presented in Figure 1. However, it may escape detection in other clinical images and also cause interpretative problems. Uniformity testing reveals the characteristics and pattern of this artifact and the so-called terminology of “picture-in-picture artifact.” As it is evident in Figure 1, typically, the artifactal spot appears at the projections, in which the gallbladder, as the region with the highest activity concentration in myocardial perfusion SPECT images, is visualized intensely. As predicted, the artifactual spot was superimposed on the LV. At first glance, the spot may be appeared confusing and mysterious to the interpreter. A localized zone of hypertrophied myocardium, say papillary muscle, or an avid intrathoracic lesion around the heart may be considered. Reviewing cinemographic images and the predictable pattern of this artifact reveal the mystery. In addition to the fixed relative location of two spots, other clues that help to differentiate artifacts from a real lesion are synchrony of the intensity or brightness of two spots and disappearance after emptying the gallbladder. However, extra care should be taken to avoid confusion with the seen of contamination. However, this issue is of less importance in tomographic imaging. It is also noteworthy that the artifact may become less visible from time to time.

In fact, this artifact originates from a failure in the hardware of the imaging system, here the gamma camera. As mentioned before, an item of hardware, called DEP, was replaced for another used one with a minor malfunction. In technical terms, gamma photons emitted from the source (or patient) are collimated when passing through the collimator holes and then are absorbed in the scintillating crystal. The light photons produced are then converted into electrical pulses in photomultiplier tubes (PMTs), and then, the exact spatial position of the interaction in the crystal, which corresponds to the origin of photon emission in the patient, is determined as X and Y in Cartesian coordinate system accomplished by positioning circuits through a particular weighted combination of electrical pulses transmitted by PMTs that have received the signal. In ADAC gamma camera systems, five main electronic boards exist in the detector, of which, DEP electronics board plays a critical role in the positioning of signals. The DEP electronics board contains 34 programmable integrated complexes and is a common source of error during count acquisition.

---

**Figure 3**: A static image of a point source placed on the scanning table. (a) A smaller spot with much lower brightness is visible above and right to the source. As a negative control, when the source is removed from the field of view, no artifact is detected (b). (c) Lateral views of the source obtained with the detector rotation (d) ROI drawn on point sources (e) count density profile. (f) Three-point sources are arranged in a triangular configuration and then imaged.

**Figure 4**: (a) In the uniformity flood images, a frame-shaped pattern is seen, superimposed on the main image, which is shifted to the upper right corner, the characteristic pattern of this artifact or “picture-in-picture artifact.” As it can be seen, the results of integral uniformity and differential uniformity are far higher than the acceptable levels. (b) After replacing with a new properly functioning board, the results of uniformity tests (visual and quantitative) are acceptable.
and recording. This item receives digitized signals from the PMTs, which are provoked by an event as well as the start of an event trigger signal from the preamplifier trigger board. After the calculation of position (X and Y signals) and amplitude or energy (Z signal) of event, the data are then transmitted to Matador Correction Electronics Board which, itself, makes corrections for energy, uniformity, and linearity on the signals received from the detectors.[2,10,11]

Several quality control tests are developed and are now available for practitioners in nuclear cardiology laboratories to test gamma cameras in the routine clinical settings on a daily, weekly, or monthly basis. These tests disclose flaws or failures in the hardware and software of the imaging system to avoid possible errors in real patient studies.[3,6,12] Substantial knowledge and awareness of the clinicians and technicians of the results of quality control tests performed by the service engineers and responsible technicians, varieties of artifacts, and also this one help to avoid misdiagnosis.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

References
1. National Electrical Manufacturers Association. Performance Measurements of Gamma Cameras. Rosslyn, Virginia: National Electrical Manufacturers Association Standards Publication NU 1; 2018. Available from: https://www.nema.org/Standards/Pages/Performance-Measurements-of-Gamma-Cameras.aspx. [Last accessed on 2020 Dec 19].
2. Saha GB, editor. Performance parameters of gamma cameras. In: Physics and Radiobiology of Nuclear Medicine. New York: Springer; 2013. p. 127-51.
3. Sokole EB, Plachcinska A, Britten A, Georgosopoulou ML, Tindale W, Klett R; EANM Physics Committee, EANM Working Group on Nuclear Medicine Instrumentation Quality Control. Routine quality control recommendations for nuclear medicine instrumentation. Eur J Nucl Med Mol Imaging 2010;37:662-71.
4. Zanzonico P. Routine quality control of clinical nuclear medicine instrumentation: A brief review. J Nucl Med 2008;49:1114-31.
5. International Atomic Energy Agency Quality Control Atlas for Scintillation Camera Systems, Vienna: International Atomic Energy Agency; 2003. Available from: http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1141_web.pdf. [Last accessed 2020 Feb 01].
6. Quality Assurance for SPECT Systems. Vienna: International Atomic Energy Agency; 2009. Available from: http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1394_web.pdf. [Last accessed 2020 Feb 01].
7. O’Connor MK. Instrument- and computer-related problems and artifacts in nuclear medicine. Semin Nucl Med 1996;26:256-77.
8. Kasner DL, Spieth ME. The day of contamination. J Nucl Med Technol 2003;31:21-4.
9. Kumar N, Verma S, Singh RKR, Datta D, Kheruka SC, Gambhir S. Contamination, a major problem in nuclear medicine imaging: How to investigate, handle, and avoid it. J Nucl Med Technol 2017;45:241-2.
10. ADAC Laboratories. Matador electronics overview manual, 9202-0104 Rev A. In: Vertex Matador Field Service Kit. Milpitas, CA: ADAC Laboratories; 1997.
11. Cherry SR, Sorenson JA, Phelps ME, editors. The gamma camera: Basic principles. In: Physics in Nuclear Medicine. Philadelphia: Elsevier Saunders; 2012. p. 195-208.
12. Dorbala S, Ananthasubramaniam K, Armstrong IS, Chareonthaitawee P, DePuey EG, Einstein AJ, et al. Single photon emission computed tomography (SPECT) Myocardial Perfusion Imaging Guidelines: Instrumentation, acquisition, processing, and interpretation. J Nucl Cardiol 2018;25:1784-846.