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Feasibility of myocardial perfusion imaging studies in morbidly obese patients with a cadmium-zinc-telluride cardiac camera

Anna Budzyńska, Sebastian Osiecki, Andrzej Mazurek, Stanisław Piszczek, Mirosław Dziuk
Military Institute of Medicine, Warsaw

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BACKGROUND: A novel cardiac SPECT camera with cadmium-zinc-telluride (CZT) based technology has a fixed array of semiconductor detectors paired with pinhole collimators focused on the heart. Image acquisition in obese patients can be challenging because of much smaller detector field of view compared to conventional gamma cameras. The aim of this study was to evaluate the impact on high body mass on the feasibility of CZT myocardial perfusion imaging (MPI). The additional aim was to investigate the mechanism of the banana-shaped/obesity artifact, as referred to in literature, and to attempt at simulating it on a phantom study.

MATERIAL AND METHODS: Study group consisted of 43 patients with morbid obesity (BMI ≥ 40 kg/m^2). All these patients underwent myocardial perfusion imaging on both CZT cardiac camera and general purpose SPECT/CT gamma camera. Control group consisted of all patients who underwent myocardial perfusion imaging on CZT camera throughout one calendar year and whose BMI was lower than 40 kg/m^2. In this group, all repeated studies were re-analyzed for estimating the frequency of heart mispositioning in the camera field of view. The number of studies performed was 1180. A static cardiac phantom was used to simulate a banana-shaped artifact. A series of phantom acquisitions during which the phantom position was altered in the camera field of view was performed.

RESULTS: In control group, 3.7% of all cardiac scintigrams required repetition, 18.9% of which were repeated due to wrong heart positioning; median BMI in this group of patients was 36.0. A banana-shaped artifact was observed in one female patient with BMI 36.0. In morbid obesity group, 32.6% of the studies were non-diagnostic with "truncation effect" on Scan Quality Control (QC). Median BMI in patients with diagnostic scans was 42.0, while in patients with not acceptable quality control test it was 45.0 ($p < 0.05$). Banana-shaped artifacts were observed in 5 non-diagnostic studies. In a phantom study an artifact of banana shape was obtained when gantry was distant from the phantom and target was on the edge of the camera field of view and was slightly truncated.

CONCLUSIONS: Problem with heart mispositioning during imaging on the CZT camera affects less than 1% of all performed studies. Morbid obesity is not a contraindication to perform myocardial perfusion scintigraphy with the use of a CZT camera because over 2/3 of the studies of very obese patients is diagnostic.

KEY words: obesity, BMI, myocardial perfusion imaging, CZT, cardiac camera, image artifacts

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Introduction

Myocardial perfusion imaging (MPI) has an established position in ischemic heart disease diagnostics. New generation of semiconductor gamma-cameras dedicated for cardiac imaging became a milestone in the way nuclear cardiac imaging is performed. Novel cardiac camera designs have in common that all available detectors are focused to imaging myocardium. The GE Discovery NM 530c uses Alcyone technology, consisting of a fixed array of solid-state cadmium-zinc-telluride (CZT) detectors paired with pinhole collimators simultaneously imaging the heart. With this camera SPECT acquisition is performed without detector's motion [1]. Main advantages of these systems (compared to

Correspondence to: Anna Budzyńska, Military Institute of Medicine, Szaserów 128 Street, 04–141 Warsaw, Poland; e-mail: abudzynska@wim.mil.pl

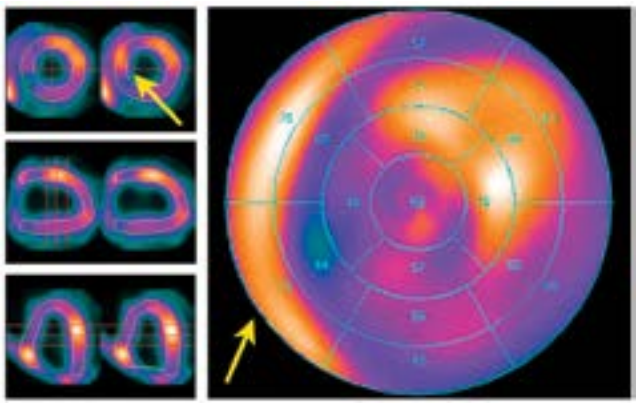

Figure 1. Male patient with BMI = 38. Banana-shaped artifact presented on polar map and short axis scans

conventional scanners) are physical parameters: higher sensitivity, higher energy resolution and better spatial resolution. The CZT technology has enabled reducing both administered activity and acquisition time with preserved high image quality [2], providing clinical information equivalent to conventional SPECT myocardial perfusion imaging [3].

Obtaining good quality, diagnostic myocardial perfusion SPECT images with use of semi-conductor systems and pinhole collimators focused on heart requires heart positioning in the center of the field of view. The volume in which the heart needs to be positioned to be imaged correctly is named the quality field of view (QFOV). This is the volume that represents the intersection of all the 19 views from each pinhole [4]. Accurate reconstruction is performed only within this volume of interest. Due to significantly smaller field of view of Discovery NM 530c compared to conventional cameras appropriate heart positioning could be challenging, especially in obese patients. Literature data indicates that image quality degradation from obesity in patients with BMI of 40 kg/m2 and above is so significant that those patients should be scheduled for MPI scanning on a conventional SPECT camera [5]. However, literature on the topic of MPI in morbidly obese patients is limited. Our seven years of experience with GE Discovery NM 530c indicate, that while correct heart positioning in patients with BMI ≥ 40 is indeed difficult, in most of cases results are diagnostically useful and imaging with conventional SPECT gamma-camera is not necessary.

The aim of this study was to present our experience and evidence that MPI in morbidly obese patients (BMI ≥ 40 kg/m^2) performed with CZT scanner in most cases allows accurate diagnostics. The second aim was to determine the frequency of heart positioning outside the quality field of view and compare it in groups of patients with BMI ≥ 40 kg/m^2 and BMI < 40 kg/m^2.

The additional aim was to investigate the mechanism of the banana-shaped/obesity artifact (Fig. 1), as referred to in literature [5], and to attempt at simulating it in a phantom study.

Materials and methods

Study population

Study group consisted of 43 patients with morbid obesity (BMI ≥ 40 kg/m^2), stage 3 according to WHO classification (Tab. 1). Studies have been performed in three consecutive calendar years.

Table 1. WHO classification of obesity [6]

BMI [kg/m^2]	WHO classification
< 18.5	underweight
18.5–24.9	normal weight
25.0–29.9	overweight
30.0–34.9	class I obesity
35.0–39.9	class II obesity
≥ 40.0	class III (morbid) obesity

Figure 2. Cardiac phantom positioned on the CZT scanner table

All patients underwent MPI on both Discovery NM 530c and general purpose SPECT-CT GE Infinia 3/8''HWK.

Control group consisted of all patients who underwent MPI on Discovery NM 530c throughout one calendar year and whose BMI was lower than 40 kg/m^2. In this group all repeated studies were re-analyzed for estimating the frequency of heart positioning outside the quality field of view. The number of studies performed was 1180. The correctness of heart positioning was assessed with the Scan Quality Control (QC) tool and qualitatively with the use of Myovation application.

Phantom study

A series of acquisitions of static cardiac phantom was performed (Fig. 2). Phantom equipped with reservoir filled with isotope enables left ventricle imaging simulation. It was attached to the frame and placed in the cylindrical vessel filled with water. No external activity was simulated. To attain a banana-shaped artifact the phantom positioning in the field of view was altered between consecutive acquisitions. Synchronous reallocation in x and y axis was accomplished with „camera out" function — automatically moving the gantry away from the phantom. The detector radius values were set as follows: 183, 185, 187, 191, 194, 214 and 221 mm.

Image acquisition and reconstruction

All patients underwent MPI scanning on GE Discovery NM 530c scanner in supine position with hands above the head. 76.7% of patients with morbid obesity and approximately 95% of patients belonging to the control group had additional imaging in prone position. In case of non-diagnostic scans in cardiac-dedicated camera

we analyzed whether patient repositioning enabled obtaining diagnostic images. Injected radiopharmaceutical (99mTc-MIBI) activity in control group was determined empirically and ranged from 8 to 20 mCi depending on body mass. Patients with BMI ≥ 40 kg/m^2 were scheduled for conventional gamma-camera imaging as well, therefore injected activity in this group was 25 mCi. For CZT camera time between injection and imaging was approximately 60 min. Two day Stress/Rest or, if feasible, Stress-only protocol were employed. Rest MPI was omitted in patients without perfusion abnormalities on stress supine and prone myocardial perfusion scintigraphy [7]. Acquisition time for both Stress and Rest study was 5 min. The images were reconstructed on a dedicated GE Xeleris 3 workstation applying a MLEM iterative reconstruction algorithm. The software GE Myovation for Alcyone was used for image reconstruction and a Butterworth filter (cut-off 0.37 cm-1, power value 7) for post-processing of the reconstructed axial slices was applied. All MPI scans were reconstructed in standard axes and polar maps of perfusion were generated using the software package [4, 5].

Phantom acquisitions were performed with standard myocardial perfusion protocol. Digital reconstruction and image analysis was performed – like in patient studies – with dedicated software: GE Myovation for Alcyone.

Scan Quality Control and Image Analysis

In every study raw data projections from 19 detectors with the Scan QC tool supplied by the vendor of the CZT camera were analyzed. Scan QC enables to asses correctness of heart placement in the field of view. Patient's heart (left ventricle) has to be positioned in the center of the QFOV without truncation. Scan QC image analysis is necessary element of cardiac imaging procedure and is performed by physician before patient is dismissed home to assure repositioning and re-imaging option if necessary.

Quality control with Scan QC tool was performed in all of morbid obesity patients. Scan QC in control group was reassessed only if re-imaging was necessary — in that case both original study and repeated study were analyzed. Performing multiple acquisitions in the same patient was caused by extra-cardiac activity denying appropriate perfusion assessment or heart positioning outside the quality field of view. Scan QC analysis allowed the frequency of heart mispositioning to be determined and compared in both groups of patients. All studies with Scan QC assessment performed — regardless of the outcome — were post-processed using Myovation for Alcyone software. Images in short and long axis as well as polar maps were analyzed for visual assessment of banana-shaped artifact presence and truncation in VLA and HLA axis, which correspond to this phenomenon [5].

In phantom study, both raw projections in Scan QC and reconstructed images presented in slices and polar maps were analyzed for verification of phantom reallocation in the field of view and truncation simulation.

Statistical analysis

Descriptive statistics (median, interquartile range [IQR]) as well as statistical tests were performed using Statistica software version 12 (StatSoft). The Mann-Whitney U test was used to check for significant differences in median BMI value between two patient groups (morbid obesity group and control group). A P-value of less than 0.05 was considered statistically significant.

Table 2. The numbers of diagnostic and non-diagnostic stress and rest studies on Discovery NM 530c

	Stress study	Rest study
Diagnostic MPI (positive Scan QC)	23 (10M)	6 (3M)
Non-diagnostic MPI (negative Scan QC)	9 (6M)	5 (3M)

Results

Control group

In one calendar year (2017) total of 1180 MPI studies have been performed. Analysis revealed that 44 cases (17 stress MPI and 27 rest MPI) required repetition; that is 3.7% of all cardiac scintigrams in analyzed year. Thirty-seven studies (14 stress MPI and 23 rest MPI) were repeated due to extra-cardiac activity. In remaining seven (3 stress MPI and 4 rest MPI) the reason of repetition was heart positioning outside the quality field of view or truncation. This represented 18.9% of repeated studies and 0.6% of all studies.

Among scans repeated due to heart mispositioning 3 single and 4 double repetitions have been noted. All single repetitions resulted in acquiring diagnostic scans on Discovery NM 530c after repositioning. When multiple repetitions were required, in one case diagnostic scans on CZT camera were not achieved, due to difficulties in correct positioning in the field of view. It was stress study in patient with BMI 34.4. Diagnostic study (although non-gated) in this patient was achieved in prone position.

Median BMI value in group of patients in whom repetition was due to heart mispositioning in the field of view was 36.0 (IQR = 9.1). In 3 patients BMI indicated 1st degree obesity, in 4 patients 2nd degree obesity.

In studies with negative Scan QC result banana-shaped artifact was observed in one patient (stress MPI) — a female with BMI of 36.0. In additional scans of this patient (2 repetitions) the artifact was not present.

Morbid obesity group

The majority of 43 studies of patients with 3rd degree obesity were stress MPIs (74.4%). There were 29 (13M) technically correct scans with positive Scan QC in first attempt, which represented 67.4% of all studies in this group. Fourteen (9M) studies (32.6%) were non-diagnostic with "truncation effect" on Scan QC (Tab. 2).

Median BMI value in 3rd degree obesity group was 43.0 (IQR 4.9). Median BMI in patients with diagnostic scans was significantly lower than BMI of patients, whose study failed quality control test (42.0, IQR = 3.0 vs. 45.0, IQR = 7.0, $p < 0.05$).

Analysis of repeated studies in this group revealed that only four patients had additional scanning after repositioning on CZT camera. In the majority of cases (71.4%) patients were referred directly to conventional dual-head SPECT gamma-camera. Of four repeated studies on CZT scanner, in 1 case diagnostic images were acquired after repositioning.

Banana-shaped artifacts were observed in 5 non-diagnostic studies (4 stress MPI, 1 rest MPI): 4 original (first attempt) scans and one repeated scan (in original scan in this patient artifact was not present).

Median BMI of patients whose study was non-diagnostic due to mispositioning, with banana-shaped artifacts on polar maps was 49.0 (IQR = 4.1).

Phantom study

In a phantom study an artifact of banana shape was obtained when gantry was distant from the phantom (camera out) and target was on the edge of the camera field of view and was slightly truncated.

Discussion

Fiechter et al. in their work showed that in patients with BMI ≥ 40 kg/m^2, 81% of the CZT scans were non-diagnostic, mainly because the cardiac position was out of focus, causing truncation artifacts of the left ventricle [5]. Our results are different – we demonstrate that over 2/3 of MPI scans of 3rd degree obese patients (BMI ≥ 40 kg/m^2) performed with Discovery NM 530c gamma-camera is diagnostic, provided correct positioning within the field of view. BMI value and chest circumference are only approximate predictors of method feasibility in obese patient. Heart size and its location in chest are of significance as well, which is indicated by the fact, that difficulties in heart positioning in quality field of view occur also in patients with 1st and 2nd degree obesity (control group results). We also believe that technicians' experience is of great importance, which to some degree may explain discrepancies between different centers.

Limitation of our work is that out of 14 studies with negative Scan QC only, in 4 cases repositioning on CZT scanner was attempted. In one case repositioning allowed obtaining diagnostic scans. Remaining 10 patients were referred directly to conventional SPECT system for cardiac imaging.

Interestingly, Gimelli et al. in their work "Evaluation of ischemia in obese patients: Feasibility and accuracy of a low-dose protocol with a cadmium-zinc telluride camera" highlight the aspect of high quality images obtained with GE Discovery NM 530c camera in obese patients [8]. Gimelli et al. point out that although the gantry size may represent a physical limit for obese patients who cannot fit inside the device, their patients did not experience such a problem and all the patients with BMI of > 35 kg/m^2 were able to fit inside the gantry [8]. These results are concordant with our observations.

Fiechter et al. stated that after application of AC, this rate of non-diagnostic studies (81%) significantly decreased to 55% [5]. We state that CT-based attenuation correction use in a study that didn't pass quality control is in principle incorrect because it doesn't deal with source of the truncation artifact which is the incorrect heart position in the camera field of view. In our work we didn't analyze AC images, because attenuation correction has no influence on the study being diagnostic or not (of technical causes). Attenuation correction may only improve diagnostic value of already diagnostic MPI study, provided positive Scan QC result.

The banana-shaped artifact, sometimes visible on polar maps, is often associated in the literature with high BMI. Hence its other name is obesity artifact [5]. We believe that the artifact, although mostly seen in morbidly obese patients, is only indirectly connected to BMI itself. Our department's experience show that it can be observed also in patients with BMI below 40 kg/m^2, and it can be simulated with a cardiac phantom. Furthermore patient repositioning may eliminate the artifact (Fig. 3A and 3B).

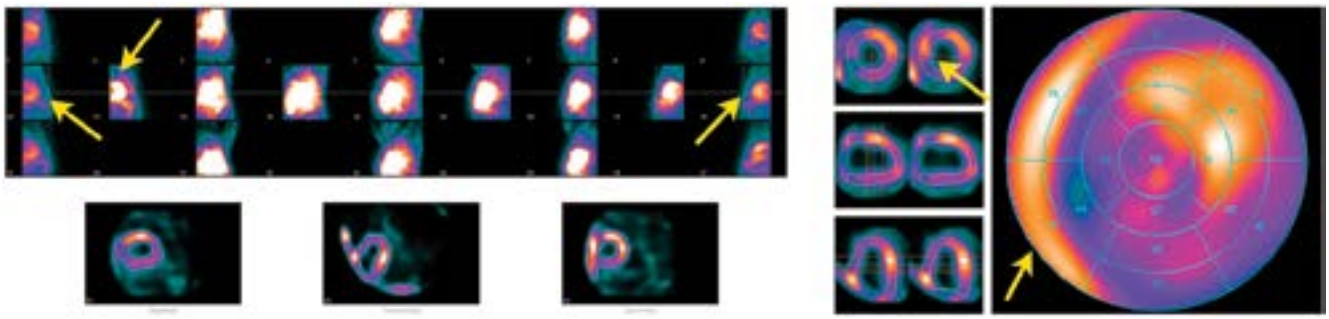

Figure 3A. Unacceptable Scan QC of patient whose polar map with banana-shaped artifact and short-axis slices were shown on Figure 1

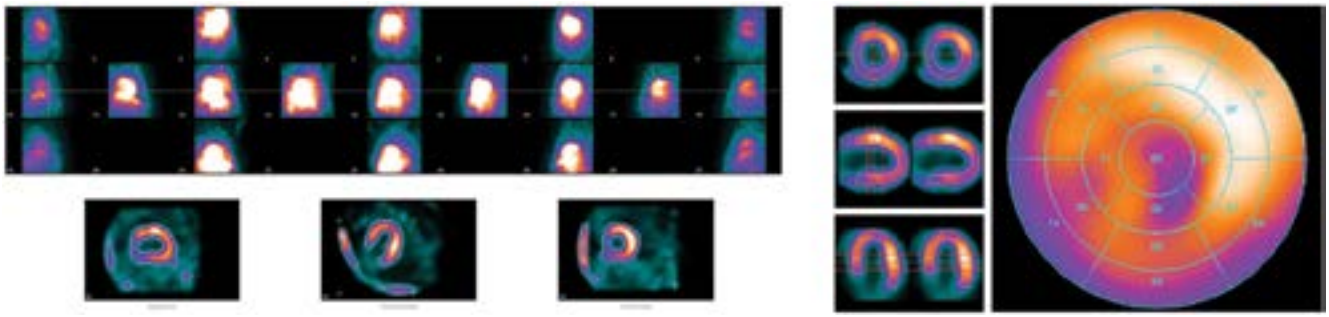

Figure 3B. Correct Scan QC of the same patient after repositioning

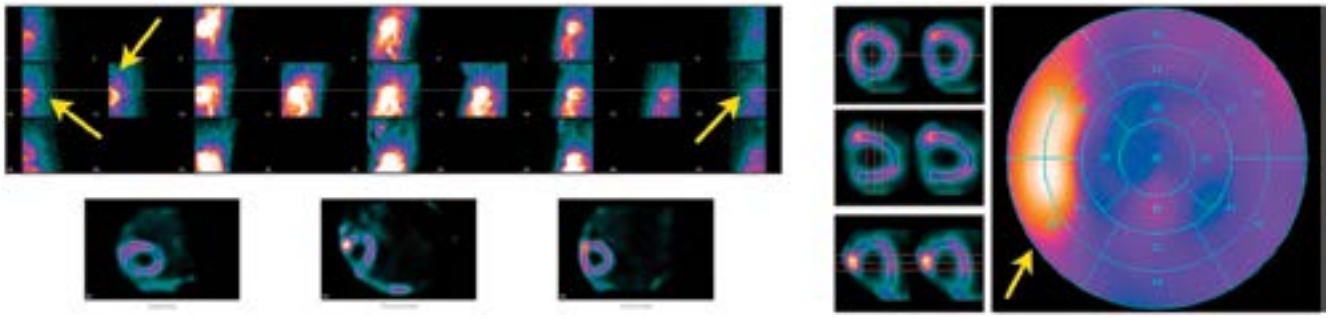

Figure 4. Unacceptable Scan QC (male patient, BMI = 44 kg/m², rest MPI); arrows indicate truncated projections (left) and banana-shaped artifact (right)

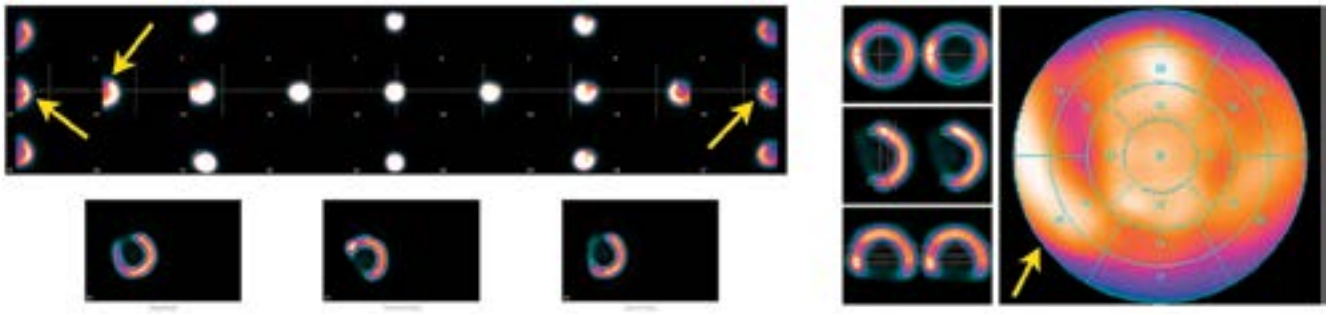

Figure 5. Scan QC of cardiac phantom, truncation on extreme projections visible (left) and banana-shaped artifact on planar map (right)

We believe that incorrect heart positioning in the field of view is essential for banana-shaped artifact presence. In all studies in which we observed this kind of artifact, there was a left ventricle truncation visible on some raw projections displayed with the Scan QC tool (Fig. 3A and Fig. 4). On the other hand, heart truncation present on raw projections does not always generate the banana-shaped artifact.

Phantom studies allowed simulation of an artifact of shape comparable to banana (Fig. 5).

Our study indicates that banana-shaped artifacts are always correlated with negative result of quality control, which highlights importance of such control in a routine practice.

Conclusions

The problem with heart mispositioning during imaging on a semiconductor gamma-camera affects less than 1% of all performed studies. High BMI is associated with difficulties in imaging. Due to the fact that over 2/3 of MPI studies of patients with morbid obesity is diagnostic, imaging on the dedicated cardiac camera with CZT detectors should be attempted in this group, rather than sending these patients directly to a general purpose gamma-camera for MPI scanning.

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