Assessment of myocardial CZT-SPECT recording in a forward-leaning “biker-like” position

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Short title: Patient positioning for cardiac-SPECT

Conflict of Interest: The authors declare that they have no conflict of interest.
ABSTRACT

Purpose. This prospective randomized study aimed at assessing myocardial perfusion imaging recorded with the high-sensitivity “D.SPECT” cadmium-zinc-telluride (CZT) camera in a forward-leaning “biker-like” position, which may potentially lower diaphragmatic attenuation as well as reduce breathing-related cardiac motions, in manner comparable to the prone position proposed with other SPECT cameras.

Methods. Patients referred to a stress-rest $^{99m}$Tc-Sestamibi protocol and positioned in the “biker” position, with the chest leaning forward on the D.SPECT camera-head at 35° from vertical, had an additional resting D.SPECT recording in supine position (n=40) or sitting position with the back rearward at 30° from vertical (n=40). Segments with attenuation artifacts were defined as those with < 65% uptake but with strictly normal contractility at Gated-SPECT and no defect reversibility from stress images.

Results. The biker position was associated with: 1) lower heart-to-detector distances than supine or sitting positions (both p<0.001), 2) lower cardiac motion amplitudes, assessed on panograms, than the supine position (p<0.001) and 3) fewer segments with attenuation artifacts than supine (on average, 1.10±1.01 vs. 1.90±1.74, p=0.010) and sitting positions (0.75±0.93 vs. 1.38±1.60, p=0.011).

Conclusion. Myocardial perfusion images from D.SPECT are enhanced for patients positioned in a forward-leaning “biker-like” position comparatively to sitting or supine positions, with a notably lower rate of attenuation artifacts.

KEY WORDS: myocardial perfusion imaging (MPI); CZT camera; left ventricular function; attenuation artifacts; patient position.
INTRODUCTION

Myocardial perfusion SPECT imaging is commonly performed with patients in the supine position and the left or both arm(s) above the head. Unfortunately, the resulting images may be hampered by a diaphragmatic attenuation of the inferior wall, constituting a source of false-positive results, even with the more recent cardiac cadmium-zinc-telluride (CZT) cameras (1-5).

These attenuation artifacts may be recognized through a particular pattern involving fixed perfusion defects but, unlike myocardial infarction, without any contractility abnormality at gated-SPECT (6,7). However, this pattern does not allow the identification of all attenuation artifacts (7), with the need that patient positions, and thus attenuation artifacts, should be exactly the same on rest- and stress-SPECT.

Computed tomography (CT)-based techniques of attenuation correction are increasingly used in this setting (7,8). They are however associated with an increase in patient irradiation, as well as with possible additional artifacts due to the inherent difficulties in matching the SPECT and CT images obtained in very different conditions (8).

Attempts to eliminate artifacts by imaging in the prone position have also been extensively reported (2,5,9-13), with an efficiency not very far from that obtained with the CT-based method for preventing inferior attenuation artifacts (5) and with the additional advantage of limiting certain breathing-related artifacts (cranial cardiac drift (12)). However, this method has the disadvantage of being somewhat uncomfortable and has been reported to produce anterior attenuation artifacts (11,13). As a result, imaging protocols mixing SPECT recordings in different positions have been developed and proven relatively efficient (9,11,14), although the latter may be difficult to associate with the somewhat long recording times of low-dose protocols.

Prone position may not be proposed to patients when recording with the “D.SPECT” camera because of the particular geometry of this camera. It may however be replaced by a forward-leaning
position, similarly to the biker position on a motorbike and previously shown to provide a high diagnostic accuracy in low-dose stress-first protocols (15). We hypothesized that this “biker-like” position may potentially lower diaphragmatic attenuation as well as the amplitude of breathing-related cardiac motions, similarly to that documented for the prone position. However no direct comparison has been conducted to date with the supine or sitting positions, which are currently proposed with the D.SPECT camera. The present prospective randomized study therefore aimed at assessing myocardial perfusion imaging recorded with the “D.SPECT” CZT-camera in the forward-leaning “biker” position, with head-to-head comparisons with more conventional recordings proposed in supine or sitting positions.

MATERIALS AND METHODS

Study population

The study patients were prospectively selected in our department on the basis that: 1) they had been routinely referred to our department for a single-day stress-first 99mTc-Sestamibi SPECT protocol performed with a high-sensitivity CZT camera (D.SPECT camera, Spectrum Dynamics) (15,16), 2) a resting SPECT was subsequently indicated based on the analysis on the initial stress SPECT images (15), 3) they were in sinus rhythm, without significant arrhythmia and left bundle branch block, and 4) they accepted to participate and to sign the informed consent form.

As a part of the study protocol, the routine resting SPECT recorded in the biker position was immediately followed by an additional resting SPECT recording set either in a supine position, if they were investigated during a week with a paired number, or in a back-leaning sitting position if they were investigated during a week with an unpaired number.

The protocol was approved by an Ethics Committee (CPP agreement n° 16.04.01) and released on the ClinicalTrials.gov site under the identifier NCT02872545.
**Stress Tests and Tracer Injection**

The stress tests were performed as described previously (15,16), with exercise performed in the upright position on a bicycle ergometer and/or with a pharmacological test conducted with dipyridamole (0.56 mg.kg⁻¹) or regadenoson (400 µg).

The ⁹⁹mTc-Sestamibi activities injected at stress ranged between 80 to 260 MBq according to body weight as previously described in detail elsewhere (15). The ⁹⁹mTc-Sestamibi activities injected at rest were 3-fold higher than those injected at stress, although no rest injection was routinely scheduled when the stress SPECT and gated-SPECT images were deemed as definitely normal (15).

**Acquisition and Reconstruction of D.SPECT Images**

The ECG-triggered SPECT acquisitions were initiated approximately 30 to 60 min after tracer injection with the patient being seated in a forward-leaning position, resembling that of a motorbike rider (15). As detailed in the Supplemental Figure 1, the patients were set astride the armchair of the camera, the chest wall leaning on the camera head commonly orientated at 35° from vertical, the patient's back being set with the arms placed orthogonal to the thorax.

As already detailed elsewhere (15,16), time-per-projection was set to target the recording of approximately 500 myocardial kcounts, leading to limit the recording times to no more than 10 min for stress-acquisitions and to almost 4 min for rest-acquisitions.

The routine resting SPECT recording in the biker position was immediately followed by an additional resting SPECT recording with the same parameters, except that patients were set either in a strictly supine position with the left arm placed away from the field-of-view (Fig. 1) or in a back-leaning sitting position with the back rearward at 30° from vertical, as currently proposed for this camera (17) (Fig. 1).
Image reconstruction was conducted by using the parameters already described elsewhere for SPECT (15) and gated-SPECT (16).

**Analysis of D.SPECT Images**

The D.SPECT data, used to address the study aim, were collected by a single experienced observer, and the results from a second observer were used for reproducibility assessment. These analyses involved a combined assessment of the stress- and rest-SPECT images presented in random order and blinded manner, without prior knowledge of any other medical data or on the position in which the resting SPECT was recorded. A total of 160 combined assessments of stress- and rest-SPECT images were considered in these analyses since each of the 80 patients had two sets of rest-SPECT images.

The segmental LV analysis was performed with a 17-segment model (Fig. 2), with exclusion of the two proximal septal segments, corresponding to the outflow tract and membranous septum, and with the image display provided from the Quantitative Gated SPECT (QGS) and Quantitative Perfusion SPECT (GPS) software (Cedars-Sinai Medical Center) (15,16). As previously detailed, myocardial perfusion was assessed visually by using a 4-point grading system and only segments with a moderate to severe reduction at stress were considered corresponding to an abnormal stress uptake (15). Of these, segments with reversible defects, and thus corresponding to a pattern of ischemia, were defined as those with an increase in uptake score on the rest acquisition (15). The other stress-defect segments were considered to have a fixed defect, likely corresponding to a pattern of myocardial infarction when the segment’s contractility was also found abnormal at gated-SPECT (15).

Segmental contractility was assessed through a combined analysis of wall motion and of the systolic increase in myocardial count, a method that compares well with results from cardiac MRI, as previously shown with the same camera (16).
Segments with a high probability of attenuation artifacts were additionally defined on the resting SPECT acquisitions as those showing: 1) a decrease in the $^{99m}$Tc-Sestamibi uptake, defined as a mean uptake $< 65\%$ of the maximal LV voxel value, a threshold currently used to identify areas with myocardial infarction on rest-SPECT (18,19), 2) no pattern of ischemia (i.e. no reversibility from stress defects) and 3) a strictly normal contractility at gated-SPECT (i.e. with motion and thickening both deemed definitely normal (16)).

Three additional parameters were extracted from each resting SPECT recording: 1) a tomographic count sensitivity in the LV area, expressed in recorded counts per min and per MBq of injected activity (20,21); 2) a heart-to-detector distance, which was computed as the distance between the middle part of the camera head (i.e. the angle setting between the 2 half-parts) and the coordinate of the center of the elliptic area placed around the LV prior to SPECT recording (see Fig. 1)); 3) the amplitude of the longitudinal cardiac motions, which was assessed according to the mean amplitude of the changes in the upper limit of the LV signal on panograms. The latter are quality control images provided in routine for detecting longitudinal heart displacements with the D.SPECT. More precisely, the counts from all detectors are summed and represented through contiguous vertical lines for each of the 120 consecutive projection positions, each projection lasting approximately 2 seconds during resting SPECT (see Fig. 1)). This mean amplitude of longitudinal motions was scored visually with the help of a graded scale and a 4-point grading system: 1: $< 5$ mm; 2: $\geq 5$ and $< 10$ mm; 3: $\geq 10$ and $< 15$ mm and 4: $\geq 15$ mm.

**Statistical Analysis**

Continuous variables are reported as mean ± SD and categorical variables as percentages. Analysis of inter-observer reproducibility of segment classification was assessed through an analysis of concordance with kappa-values. Unpaired and paired comparisons between continuous variables were performed with the Mann-Whitney and Wilcoxon rank sum tests respectively, while unpaired
comparisons between categorical variables were performed with Chi-square tests. For all tests, a p value < 0.05 was considered to reflect a significant difference.

RESULTS

Patient characteristics are summarized in Table 1 for the overall study population, as well as for the two “supine” and “sitting” subgroups. Mean age was 62 ± 10 years, 24 (30%) were obese (as defined by a body mass index > 30 kg.m\(^{-2}\)), 15 (19%) were women of whom only 5 (6%) were obese. Patients from the sitting subgroup exhibited a moderately older age with a lower proportion of women when compared with those from the supine position subgroup (Table 1).

Reproducibility between the 2 observers was close to excellent with a global Kappa score of 0.74 for identifying the segments showing a pattern of attenuation artifact. This reproducibility was good to very good for the identification of segments showing a pattern of ischemia or of infarction with respective Kappa scores of 0.55 and 0.71.

Among the total 2400 analyzed segments (15 segments for each of the 160 sets of stress and rest images), 205 (8.5%) had a pattern of attenuation artifact. Up to 86% of these attenuated segments were located in a large inferior area, whereas the remaining 14% were located in an anterior and apical area. These 2 attenuation areas are displayed on the schematic representation of the 17-segment model in Figure 2.

As detailed in Table 2, there were no significant differences between the SPECT results obtained with the biker position and with the sitting or supine positions with regard to the mean number of segments identified as having a pattern of ischemia or infarction. By contrast, the mean number of segments showing a pattern of attenuation artifact was markedly lower with the biker position comparatively to the supine (1.10±1.01 vs. 1.90±1.74, p=0.010) or sitting positions (0.75±0.93 vs.
1.38±1.60, p=0.011). These differences remained significant when the analyses were restricted to the inferior attenuation area defined above, but not when restricted to the anterior and apical attenuation area, although the comparison between biker and supine positions was at the borderline of significance for the latter (p=0.08) (Table 2).

A mean segmental uptake value was computed for each LV segment, after having excluded all those associated with a pattern of ischemia or infarction on analyses obtained with either the biker, supine or sitting rest SPECT-images. The uptake values of these normally perfused segments are displayed through plot boxes in Figure 2, yielding evidence of higher uptakes with the biker than with the sitting or supine positions for several segments, particularly those located in the proximal part of the inferior attenuation area.

As depicted in Table 2, the biker position was additionally associated with lower heart-to-camera head distance than supine and sitting positions (both p<0.001), as well as with lower count sensitivity and lower LV longitudinal motion amplitudes than the supine position (p≤0.001).

These results are illustrated in Figure 1 by representative examples of SPECT images obtained in 2 patients for whom the additional rest-SPECT were recorded in sitting or supine position, as well as in the Supplemental Fig. 2 where SPECT images from an overall recording protocol are displayed (biker stress-, biker rest- and supine rest-SPECT).

**DISCUSSION**

In spite of their improved performance characteristics, cardiac CZT cameras are still considered to provide suboptimal specificity for identifying significant coronary artery disease (22) and attenuation artifacts potentially play a substantial role in this setting. Indeed, attenuation artifacts are at least as severe with Anger cameras as with CZT cameras (1) and, to date, are far from being fully prevented and/or detected by the various methodologies and strategies elaborated for this purpose (2-15).
In the present prospective randomized study conducted with the D.SPECT CZT camera, attenuation artifacts were shown to be strongly reduced in patients positioned in a semi-reclining “biker-like” position comparatively to the more conventional sitting and supine positions. This biker position was initially developed as an equivalent of prone position, adapted to the particular geometry of the D.SPECT camera for which image recording may not be proposed in prone position. This position is seemingly more comfortable than the prone position with the patient’s shoulders being less stretched back and breathing less affected by lung compression due to thoracic weight. In our experience, the biker position is well tolerated, even in patients with severe left ventricular dysfunction. No more than 5% of the patients referred in our department for a myocardial perfusion SPECT are unable to complete this exam in the biker position, mostly due to an extreme physical exhaustion and moreover to hip problems hampering their sitting astride the camera armchair.

As detailed in Table 2 and Figure 2, this biker position was shown herein to reduce myocardial attenuation and corresponding artifacts, as compared with the sitting or supine position, with this reduction mainly involving the basal portion of the inferior area, similarly to that previously reported for the prone versus the supine position.

As observed on the left ventricular projection profiles in Figure 1, this reduction in inferior attenuation was moreover associated with easier delineation and separation of the inferior LV wall from the attenuating subphrenic organs. This observation can be partly explained by an upward LV displacement, as previously documented for prone comparatively to supine positions (23). The biker position was additionally associated with a trend toward a lower rate of anteroseptal and apical defects, as compared with the supine position, together with a higher normal segmental uptake in the proximal and median portion of the anterior wall (segments # 1 and 7 in Figure 2). This observation is in contrast to higher attenuation rates documented for the prone position in the anterior area (11,13). The normal segmental uptake of the same proximal and median portion of the anterior wall was found even higher with the sitting position (Fig. 2), strengthening the general consideration that the
different patient positions lead to specific attenuation patterns and are thus not interchangeable for further patient monitoring.

The biker position was associated with two additional properties that could further favor image quality. As already stated above, the first is the small amplitude of longitudinal cardiac motions. This property, which was also observed for the sitting position herein, may likely be explained by lower amplitudes of breathing-related diaphragmatic motions, as already documented for upright versus supine positions in previous MRI and ultrasound studies (24,25). According to the scores obtained from panograms herein (Fig. 1), this longitudinal LV motion did not exceed 5 mm on average for both upright sitting and biker positions, whereas it ranged between 5 and 10 mm for the supine position. While the true clinical impact of this finding remains to be properly defined, it may be hypothesized to play an additional role to that of the upward LV shift, in the enhanced separation documented with the biker position between the inferior wall and subphrenic organs.

A second additional property of the biker position, also likely to enhance spatial resolution, is a lower heart-to-detectors distance (18 cm, on average), when compared with the 2 other patient positions (20 cm, on average). Indeed, in the biker position, the anterior chest walls directly lean on the surface of the camera head. By contrast, the camera head needs to be placed at a few centimeters distance from the anterior chest wall in the sitting and supine positions.

On the other hand, an almost 10% lower tomographic count sensitivity was documented in the present study for the biker position relative to the supine position. This decrease is likely explained by the short heart-to-detectors distance, leading to the positioning of the LV in an area where count sensitivity is slightly lower than in a more remote area, a property that was confirmed by further phantom experiments (results not shown).

A limitation of the study is that the presence of attenuation artifacts could not be further strengthened by the absence of any coronary stenosis at angiography. Only few patients had a subsequent coronary angiography especially among those mainly exhibiting attenuation artifacts. However, in a previous report, the sensitivity for identifying patients with coronary stenosis was found to be rather
high (88%) for stress-SPECT recorded with the biker position (15), and the rate of normal stress D.SPECT images reached 97% in patients with < 10% likelihood of coronary artery disease (normalcy rate), strengthening the general consideration of a rather low rate of artifacts with the biker position (15).

It should additionally be kept in mind that only the resting-SPECT were renewed herein for further comparisons of patient positions and that only patients with abnormal or at least doubtful stress-SPECT in our current biker position could be included. Thereby, it is likely that this study as designed does not allow precise determinations of the actual rates of attenuation artifacts, as well as diagnostic confidences and accuracies, in the different patient positions.

It must also be recognized that the majority of the attenuation artifacts could be easily identified through an expert visual analysis. However, minimizing these artifacts and improving the uptake of attenuated segments is likely suitable for better assessing myocardial ischemia and necrosis.

In conclusion, myocardial perfusion images from the D.SPECT are enhanced for patients positioned in a forward-leaning “biker” position rather than in more conventional sitting or supine positions. This enhancement involves not only a lower rate of attenuation artifacts, but also lower heart-to-detector distances and lower amplitudes in breathing-related cardiac motions. These properties are likely to favor image quality and potentially diagnostic accuracy although this latter feature remains to be further assessed in dedicated ancillary studies.
REFERENCES


Figure 1. Schematic representation of patient positions (upper panel) and of SPECT data from 2 patients belonging to the supine and sitting subgroups respectively, and who were ultimately considered as having attenuation artifacts (bottom panels). Note that the biker position provides: 1) a shorter distance between the LV and the camera head (white arrows) on axial tomographic slices, 2) a better separation of the inferior wall from subphrenic organs (red arrows) on left profile projections, 3) a lower amplitude of the longitudinal motions of the upper LV border on panograms, as compared with the supine position (see the distance separating the 2 green dashed lines), and 4) less severe inferior attenuation artifacts on polar maps.
Figure 2. Per-segment distribution of uptake values recorded with the biker position, as compared with those obtained in the same patients in either supine (upper panel) or sitting (lower panel) positions, after exclusion of segments with a necrotic or ischemic pattern (with n ranging from 32 to 40 in each segment’s group). Also shown at the bottom of the Figure is the schematic representation of the LV 17-segment model and of the inferior and anterior-apical areas where attenuated segments were identified (red color). Segments # 2 and 3, corresponding to the outflow tract and membranous septum, were excluded from these areas.

*: p<0.05 for paired comparisons in between patient's positions.
Table 1: Main characteristics of the overall study population and in the two subgroups where an additional rest-SPECT was recorded in sitting or supine position

<table>
<thead>
<tr>
<th></th>
<th>Overall study population (n=80)</th>
<th>Sitting subgroup (n=40)</th>
<th>Supine subgroup (n=40)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (years)</strong></td>
<td>62 ± 10</td>
<td>64 ± 12</td>
<td>59 ± 8 *</td>
</tr>
<tr>
<td><strong>Female gender</strong></td>
<td>15 (19%)</td>
<td>4 (10%)</td>
<td>11 (27%) *</td>
</tr>
<tr>
<td><strong>Body mass index (kg.m⁻²)</strong></td>
<td>29 ± 5</td>
<td>28 ± 5</td>
<td>29 ± 5</td>
</tr>
<tr>
<td>&gt; 30 kg.m⁻²</td>
<td>24 (30%)</td>
<td>12 (30%)</td>
<td>12 (30%)</td>
</tr>
<tr>
<td><strong>History of myocardial infarction</strong></td>
<td>27 (34%)</td>
<td>17 (42%)</td>
<td>10 (25%)</td>
</tr>
<tr>
<td><strong>History of coronary artery bypass</strong></td>
<td>9 (11%)</td>
<td>6 (15%)</td>
<td>3 (7%)</td>
</tr>
<tr>
<td><strong>History of coronary angioplasty</strong></td>
<td>33 (41%)</td>
<td>21 (52%)</td>
<td>12(30%)</td>
</tr>
<tr>
<td><strong>Recent history of chest pain</strong></td>
<td>32 (40%)</td>
<td>17 (42%)</td>
<td>15 (38%)</td>
</tr>
<tr>
<td><strong>Exercise stress test</strong></td>
<td>70 (87%)</td>
<td>33 (82%)</td>
<td>37 (92%)</td>
</tr>
<tr>
<td><strong>Pharmacological stress test</strong></td>
<td>10 (12%)</td>
<td>7 (17%)</td>
<td>3 (7%)</td>
</tr>
<tr>
<td><strong># segments with stress defects</strong></td>
<td>2.5 ± 2.7</td>
<td>3.0 ± 2.9</td>
<td>2.0 ± 2.4</td>
</tr>
</tbody>
</table>

*: p<0.05 for paired comparisons between sitting and supine half-groups.
Table 2: Paired comparisons between SPECT data recorded in the biker position and in either the sitting (n=40) or supine (n=40) position.

<table>
<thead>
<tr>
<th></th>
<th>Biker</th>
<th>Sitting</th>
<th>P value</th>
<th>Biker</th>
<th>Supine</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal motion score</td>
<td>1.3±0.6</td>
<td>1.3±0.9</td>
<td>NS</td>
<td>1.6±0.8</td>
<td>2.5±1.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Heart-to-camera head distance (cm)</td>
<td>18.3±2.3</td>
<td>20.1±2.4</td>
<td>&lt;0.001</td>
<td>18.3±1.6</td>
<td>20.2±2.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Count sensitivity (counts/min/MBq)</td>
<td>586±170</td>
<td>600±173</td>
<td>NS</td>
<td>557±152</td>
<td>609±171</td>
<td>0.001</td>
</tr>
<tr>
<td>Defect extent (mean number of segments)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ischemic pattern</td>
<td>1.58±2.31</td>
<td>1.35±2.23</td>
<td>NS</td>
<td>1.0±1.7</td>
<td>1.2±1.5</td>
<td>NS</td>
</tr>
<tr>
<td>Infarction pattern</td>
<td>1.38±2.62</td>
<td>1.40±2.28</td>
<td>NS</td>
<td>0.9±2.0</td>
<td>0.6±1.3</td>
<td>NS</td>
</tr>
<tr>
<td>Attenuation artifact pattern</td>
<td>0.75±0.93</td>
<td>1.38±1.60</td>
<td>0.011</td>
<td>1.10±1.00</td>
<td>1.90±1.74</td>
<td>0.010</td>
</tr>
<tr>
<td>- inferior attenuation area†</td>
<td>0.70±0.91</td>
<td>1.28±1.43</td>
<td>0.006</td>
<td>0.93±0.94</td>
<td>1.52±1.58</td>
<td>0.046</td>
</tr>
<tr>
<td>- anterior and apical attenuation area†</td>
<td>0.05±0.22</td>
<td>0.10±0.30</td>
<td>NS</td>
<td>0.18±0.38</td>
<td>0.38±0.70</td>
<td>0.083</td>
</tr>
</tbody>
</table>

*: corresponding to segments belonging to the inferior attenuation area described at the bottom of Figure 2.

†: corresponding to segments belonging to the anterior and apical attenuation area described at the bottom of Figure 2.

NS: non-significant with a p value > 0.10
Supplemental Figure 1. Consecutive steps applied for positioning a patient in the biker position with the patient being asked: (A) to sit astride the camera armchair, the camera head being positioned at 35° from vertical (this angle may need be markedly decreased in certain abdominal obesity patients), (B) to place the chest in close contact with the surface of the camera head and (C) to place the arms orthogonally to the thorax (C), with the result definitely resembling a biker on a motorbike (D, E).
Supplemental Figure 2. Representative SPECT images from the overall recording protocol, in a patient ultimately considered as having attenuation artifacts on the inferior walls of the supine resting-SPECT recording. Note the easier delineation and separation of the inferior wall from subphrenic organs with the biker position than with the supine position (white arrows).