ORIGINAL ARTICLE

An Assessment of Myocardial Perfusion Count Distribution Differences among Various Image Reconstruction Methods in Myocardial Perfusion Scans Using Three Head Gamma Camera

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Abstract

***Purpose*: The novel 3 Detector SPECT 'GCA-9300R' is equipped with attenuation correction algorithm of 3D-OSEM and SSPAC. The combination of this highly sensitive gamma camera with high quality techniques seems very promising concerning diagnostic value. The aim of this study is to comprehend the difference of tracer uptake in MPS under the usage of 3D-OSEM, SSPAC method compared with FBP using triple head gamma camera.**

***Methods*: We examined a total of 40 consecutive cases (20 cases for both male and females), in which conducted myocardial perfusion scans and diagnosed as no heart ischemic state. The examination was conducted under rest first 1-day protocol. Comparative analysis was conducted between FBP and 3D-OSEM (rest and stress), FBP and SSPAC (rest and stress), and FBP and prone images (stress) as well as 3D-OSEM and prone images (stress).**

***Results*: In FBP, we observed a lower count distribution in septal region, higher count distribution in apical region and apical side of the lateral region. 3D-OSEM showed slightly lower count distribution compared with FBP in the septal, lateral and a apical region. The reduction was more prominent with the males. Regarding SSPAC, in comparison with FBP, count elevations were observed in the inferior and septal regions while in the lateral and apical region the count was reduced. There was no statistically significant count difference between SSPAC and prone image in the inferior regions.**

***Conclusion*: With GCA-9300R, 3D-OSEM has the tendency toward count reduction in the septal, lateral and apical regions. On the other hand, SSPAC could reduce the count reduction in sepal and inferior regions toward FBP, and could prove to be a very helpful tool in the diagnosis of ischemia.**
Keywords: 3D-OSEM, CT-AC, Prone, SSPAC, Three head detector
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The Toshiba 3 Detector SPECT 'GCA-9300R' was released in 2014, and it was expected to make diagnostic performance superior, specializing in the head and heart regions. This novel triple head gamma camera has the structural benefit and advantage of being highly sensitive. In recent years, Japan has seen an increase in the rate of brain and myocardial region examination utilizing nuclear medicine. This new equipment will be able to meet the demand of Japanese clinicians.

Regarding the evaluation of myocardial perfusion, with

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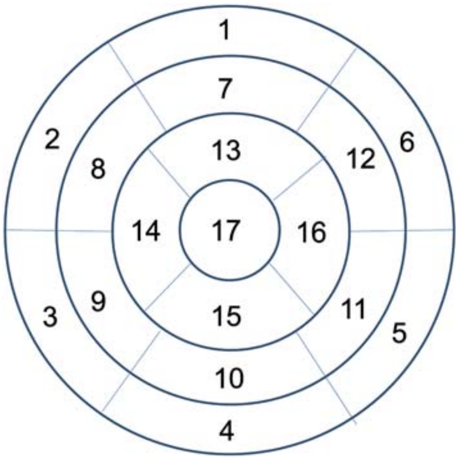

Fig. 1 The figure of 17-segment polar map.

abundant evidence based on past myocardial perfusion scan (MPS) reports, SPECT tracer is still the main method used to assess the distribution of myocardial blood supply. Unfortunately, we need to better our knowledge of the artifacts which occasionally lead to confusion. Especially the choice of technique to reduce the influence of image artifacts mainly occurring in the inferior wall of the left ventricle is selected by each institution respectively. The GCA-9300R has been equipped with three dimensional ordered subsets expectation maximization (3D-OSEM). 3D-OSEM is a three-dimensional correction method incorporating Z-axis direction correction in 2D-OSEM. It can reduce blurring caused by the distance between radiation sources and the collimator and has the benefit of allowing the availability of higher spatial resolution. Applying the SSPAC method is better for avoiding RI accumulation count reduction in inferior region with its highly sensitive settings. Regarding the inferior region, CT-based attenuation correction (CT-AC) (1) has been widely used in accordance with the gradual spread of SPECT-CT, and the positive effects are well recognized, however, the problem of over-correction still remains. The additional prone image acquisition (prone-image) has taken on the important role of differentiating between the existence of reduced blood supply and artifacts (2). The combination of spine and prone position has also been recommended (3), however the method requires the patient's position to change which takes up additional time. Choosing between these techniques has the potential to influence our diagnostic value, so a suitable choice is important depending on the circumstances. The aim of this study is to evaluate the characteristics of tracer uptake in left ventricular myocardium under the usage of 3D-OSEM and SSPAC compared with FBP under the usage of GCA-9300R.

Materials and methods

We examined a total of 40 consecutive cases (20 cases for both male and females), conducted using MPS at Showa University Hospital and diagnosed as no heart ischemic state clinically between August 2014 and August 2017. Based on diagnostic images including MPS and clinical data, the clinical diagnosis was defined by cardiovascular internal medicine physicians. The subjects underwent exercise (total n=13; m7, f6) or pharmacological (total n=27; m13, f14) stress and rest tests. In 10 of the male cases and 14 of the female cases who were conducted the MPS in the latter stage of this study, the prone images were added because they are preferable as control subjects to be compared with SSPAC.

The examination was conducted under rest first 1-day protocol. For the rest test a dose of 185 MBq of ^{99m}Tc tetrofosmin (Nihon MediPhisics, Tokyo, JP) was injected intravenously, and for the stress test a dose of 555 MBq was used. In pharmacological stress, Adenosine (Daiichi Sankyo Pure Chemicals, Tokyo, JP) was infused for 6 minutes at a rate of 140 ug・kg-1・minuets-1. A triple-detector SPECT system (GCA-9300R; Toshiba Medical Systems, Tochigi, JP) equipped with a low energy high-resolution collimator was also used. The gated SPECT data was acquired under the following parameters; 360° step-and shoot rotation; 64 × 64 matrix; 30 seconds per step; 16 frames of cardiac cycle. The cut-off frequency of the Butterworth filter was 0.25 cycle/cm.

The data was reconstructed with FBP, 3D-OSEM, SSPAC, and databases of these three sets of data as well as prone position data were created for each gender respectively. 3D-OSEM was set in 3 iterations and 10 subsets. The database was made up using 17-segment model (Fig. 1) with the software 'Heart function View' (Nihon MediPhisics, Tokyo, JP) and distribution differences of the segmental % uptake value were compared statistically. The polar map data of every patient was compiled by the software automatically, and when the included ranges seemed to be inadequate, the ranges were corrected by well-experienced radiologists. Comparative analysis was conducted between FBP and 3D-OSEM (rest and stress), FBP and SSPAC (rest and stress), and FBP and prone images (stress) as well as 3D-OSEM and prone images (stress). The differences in segmental values were originally calculated on the basis of t test. In the segments where the data did not show normal statistical distribution, the Mann-Whitney U test was used. The non- parametric multivariate analysis with Steel-Dwass procedure was also conducted. And a P value of less than 0. 05 was considered statistically significant. In this study, the regions of $p<0.05$ and $p<0.01$ were considered as mild and severe low count areas respectively. The Ethics Committee of the Showa University approved the study.

Results

The basic patients' data is shown in Table 1. Naturally the height and body weight of the males was higher than that of

Table 1 Patients' general data

	Age	Height (cm)	Weight (Kg)	BMI (Kg/m2)	EF (%)	EDV (ml)	ESV (ml)
male	70.0 ± 10.7	165.8 ± 7.63	67.0 ± 10.2	24.1 ± 2.41	63.8 ± 11	63.2 ± 14.2	25.1 ± 7.64
female	68.6 ± 16.0	153.6 ± 7.86	54.5 ± 10.3	23.2 ± 4.23	69.5 ± 10.3	49.5 ± 10.4	16.4 ± 7.20
p value	n.p.	<0.001	<0.001	n.p.	n.p.	<0.01	<0.01

BMI=body mass index
EF=ejection fraction

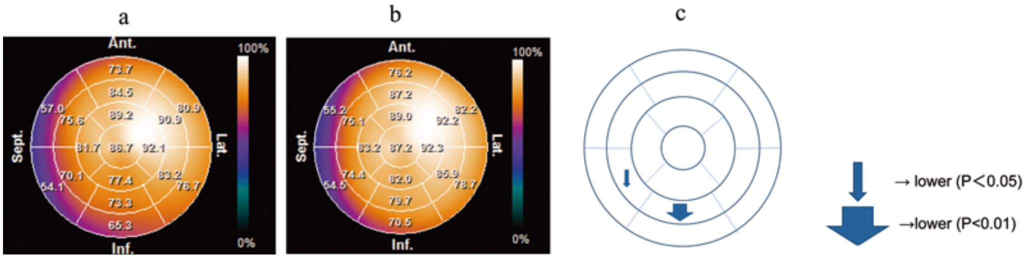

Fig. 2 Polar map with FBP reconstruction in stress test. a: male, b: female, c: statistical difference.
a, b: Perfusion counts are low in the septal region, whereas they are high in the apical region. Males showed lower value in the septal and inferior regions. In middle portion of the septal to inferior region (Seg.9, 10) The' counts was lower for males than for females with statistically significance.
c: Small arrow represents a mild difference and large arrow represents a severe difference in contrast with females' respectively.

the females', whereas the BMI was not so different. EF also showed no significant difference between the genders, although the results for the females were slightly higher than those for the males. EDV and ESV were higher in males with statistical significance. These differences can be considered within the general gender difference of the left ventricular cavity size. The average for SSS was 1.24 ± 1.31 (range 0-4).

The data was not normally distributed in following segments; seg.4 prone in female, seg.5 SSPAC at rest in male, seg. 8 3D-OSEM at stress in male and SSPAC at stress in male, seg. 10 prone image in female, seg. 12 FBP at rest in female and 3D-OSEM at stress in male, seg. 13 SSPAC at stress in female, seg.14 SSPAC at stress in female and SSPAC at stress in male, seg.16 FBP at rest in both genders.

The polar map data reconstructed in FBP at stress test is shown in Fig. 2. In FBP lower count distributions in the septal region and higher count distributions in the apical region and apical side of lateral regions were observed. The male subjects showed lower count distribution in the inferior region than with the female subjects, visually. Statistically severe differences ($p<0.01$) were observed in seg. 10 and statistically mild differences were observed in seg.9.

The acquired databases concerning mean blood supply and standard division are shown in Fig. 3. The statistical results between 2 objects among every image are shown in Fig. 4-6. 3D-OSEM showed mild lower count distribution against FBP in the lateral, septal and apical region for the males. The slight reduction in the lateral regions was observed for the females. One segment of septal region (rest) and inferior region (stress) were also observed. Totally, the lower count regions were higher for the males.

In SSPAC, severely elevated count areas were observed in septal regions and this tendency was stronger in female subjects. In the inferior region the count elevation effect was confirmed in seg.4, 10 for the females and seg.4 for the males, and among them severe count elevation was only observed in seg.10 for the females. On the other hand, in the lateral and apical region the SSPAC count was lower than FBP, and these regions area mostly matched with the original higher count distribution by FBP. These count changes were more predominant in the stress test than the rest test.

Regarding the inferior wall, there were no significant difference between SSPAC and Prone image. Prone image showed a dramatically higher count distribution in the inferior and lateral regions than FBP. Compared with prone image SSPAC, prone image showed an obviously lower count in the lateral and septal regions and higher count in septal regions.

The result of non-parametric multivariate analysis are shown in Table 2. Although the number of segment with significant difference was less than 2 comparative test, fundamental tendency was similar. The segment showing significant difference only in the analysis was not confirmed.

Discussion

In MPS, the inhomogeneous count reduction of the RI tracer is inescapable because there is the attenuation reduction, and the heart has some surrounding organs such as the lungs, diaphragm, liver, stomach and spine. The artifact commonly

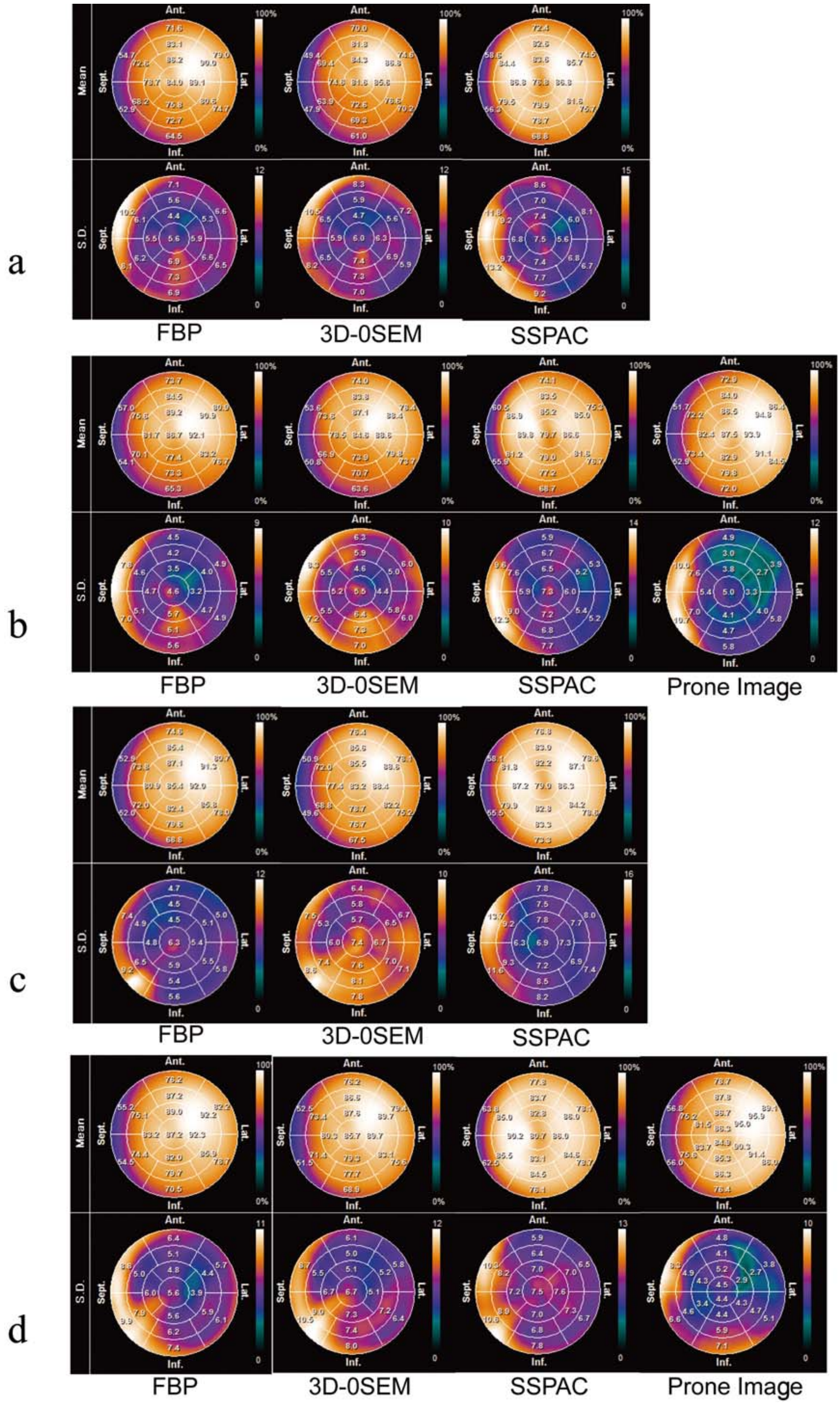

Fig. 3 Each database showing (**a**) male in rest test (**b**) male in stress test (**c**) female in rest test (**d**) female in stress test

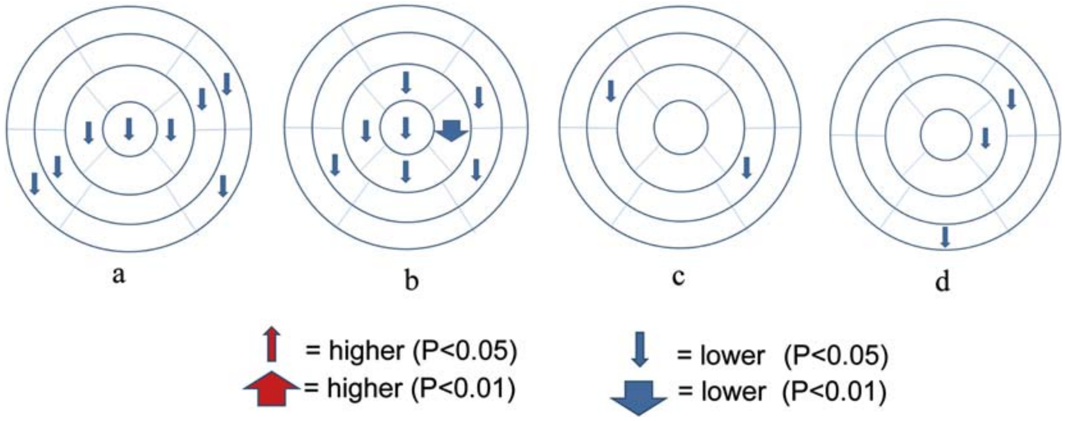

Fig. 4 Comparison between 3D-OSEM with FBP. a: Male rest, b: Male stress, c: Female rest, d: Female stress.
Count reductions were observed in the septal, lateral and apical regions. The reduction was more prominent with the males. Small arrow represents mild difference and large arrow represents severe difference respectively.

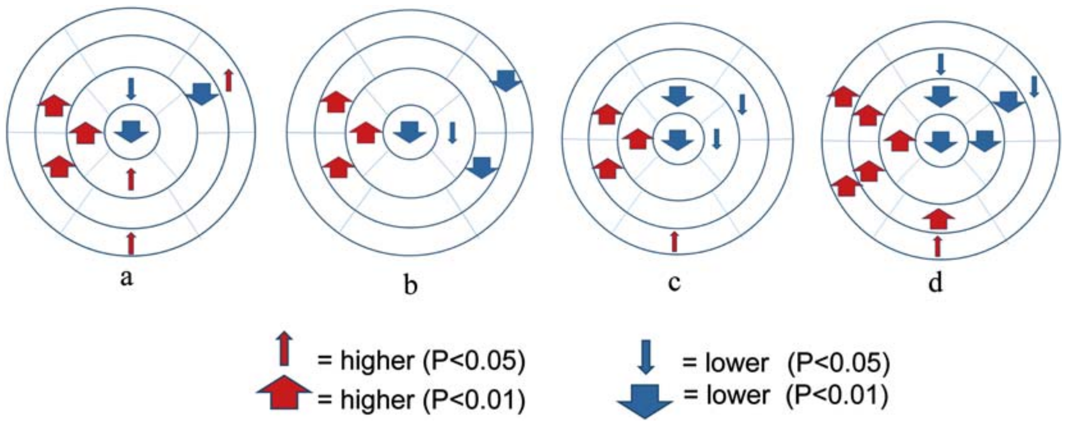

Fig. 5 Comparison between SSPAC with FBP. a: Male rest, b: Male stress, c: Female rest, d: Female stress.
Counts reductions were observed in the lateral and apical regions. The count elevations were observed in the septal and inferior regions. These tendencies were most prominent in the stress test.
Small arrow represents a mild difference and large arrow represents severe difference of SSPAC in contrast with the FBP value respectively.

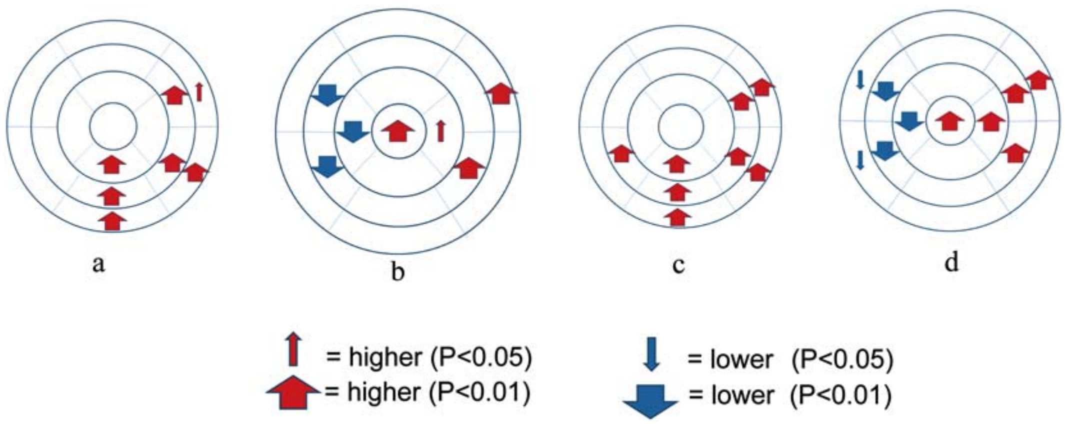

Fig. 6 Relationship with prone image in stress test. a: Male FBP vs Prone, b: Male SSPAC vs Prone, c: Female FBP vs Prone, d: Female SSPAC vs Prone.
The obvious effect of prone image elevating the counts in the inferior and lateral regions was observed. Regarding inferior regions, there were no statistically significant differences between SSPAC and prone image.
Small arrow represents a mild difference and large arrow represents severe difference of prone image in contrast with the FBP or SSPAC value respectively.

Table 2a

Seg.	FBP vs 3D-OSEM rest	FBP vs 3D-OSEM stress	FBP vs SSPAC rest	FBP vs SSPAC stress
1				
2				
3				
4				
5	○ FBP>OSEM			
6				◎ FBP>SSPAC
7				
8			◎ FBP<SSPAC	○ FBP<SSPAC
9	○ FBP>OSEM	○ FBP>OSEM	◎ FBP<SSPAC	◎ FBP<SSPAC
10			○ FBP<SSPAC	
11				
12			○ FBP>SSPAC	◎ FBP>SSPAC
13			○ FBP>SSPAC	◎ FBP>SSPAC
14	○ FBP>OSEM	○ FBP>OSEM	◎ FBP<SSPAC	◎ FBP<SSPAC
15				
16	○ FBP>OSEM	◎ FBP>OSEM		◎ FBP>SSPAC
17			◎ FBP>SSPAC	◎ FBP>SSPAC

○ → P<0.05
◎ → P<0.01

Table 2b

Seg.	FBP vs 3D-OSEM rest	FBP vs 3D-OSEM stress	FBP vs SSPAC rest	FBP vs SSPAC stress
1				
2				○ FBP<SSPAC
3				○ FBP<SSPAC
4				
5				
6				
7				
8			◎ FBP<SSPAC	◎ FBP<SSPAC
9			◎ FBP<SSPAC	◎ FBP<SSPAC
10				○ FBP<SSPAC
11				
12				◎ FBP>SSPAC
13			○ FBP>SSPAC	◎ FBP>SSPAC
14	○ FBP>OSEM		◎ FBP<SSPAC	◎ FBP<SSPAC
15				
16		○ FBP>OSEM	○ FBP>SSPAC	◎ FBP>SSPAC
17			◎ FBP>SSPAC	◎ FBP>SSPAC

○ → P<0.05
◎ → P<0.01

impedes our assessment especially in the inferior region. It was reported that in healthy subjects the accumulation reduction occurred in the inferior and septal wall with a statistically significant difference (4). The generation of an attenuation coefficient map to attenuation correction was recommended as one of the various reporting methods. Today, this technique has been mainly adapted to CT-AC (1), whereas in the past methods using an external source were attempted. Although the additional data acquisition is needed, the prone image has also been used as a preferable tool ever since the initial stage of MPS (2, 3).

The triple head gamma camera has the structural benefit and advantage of being highly sensitive. For the detector, a smaller than usual, 2-inch photomultiplier tube which is smaller than general one is adopted. The arranged density is also more than twice that of general detectors, and it contributes to linearity and uniformity. Because in the myocardial SPECT it is possible to use it with a narrow effective visual field of 38cm, the optimum visual field was realized. The 120° rotation acquisition of the triple head gamma camera is equivalent to the 180° rotation acquisition of the conventional dual head gamma camera. Therefore, in the same acquisition time the three head gamma camera can get more highly sensitive images and reduce radiation exposure by lowering the tracer dose. Regarding MPS with a conventional dual head gamma camera, the 180° rotation acquisition is more beneficial than 360° rotation acquisition due to the higher contrast resolution. However the triple head gamma camera has the ability to get enough contrast with increased image homogeneity. In addition, the compact design of GCA-9300R allows it to function in a relatively narrow area and reduce the patients' discomfort when in such an enclosed space.

The previously reported multi-center study in Japan (4) showed that compared with 180° acquired data, 360° data has the feature of lower count distribution in inferior wall for males and apical side for females. In the FBP data of our study, the lower count distribution in inferior wall was observed and there were statistically significant differences in the middle portion of the inferior region and septal (posterior side) regions. The result was matched with past results, however the lower accumulation in the apical side for females was not confirmed. These tendencies were said to be more prominent in the data reported in the USA (4, 5), and it's possible that our negative results were due to a difference in the build of our patients. They also reported on the differences of accumulation rotation between 180° and 360. The RI count distribution of 360° rotation was lower in the septal region and higher on the apical side wall than with 180° rotation. Although in this study the results were not compared with 180° data, the tendency was observed both in male and female cases. Increasing count elevation occurring on the apical side was also prominent on the apical side of the lateral wall.

OSEM has been widely used in the SPECT, because it allows for improved signal to noise ratio in the low count region and avoids streak artifact in the high count region. In clinical application, it helps us to detect the ischemia in the inferior wall in MPS, however it was also reported that it didn't contribute to an improved depiction of the inferior wall compared with FBP (6). Recently three-dimensional methods based on conventional 2D-OSEM with added collimator opening revise were introduced and from this application we can get even more improved images. The utility of 3D-OSEM in the field of SPECT has been reported (7-10). Although the effect using 3D-OSEM in MPS has not been confirmed yet, the combination of the sensitive gamma camera and the high quality correction method are expected to produce superior diagnostic imaging. However in our study, the perfusion count reduction in 3D-OSEM reconstruction becomes more prominent than in FBP. It is possible that the contrast improvement would emphasize the accumulation difference more, and low perfusion count regions in FBP would be expressed as lower perfusion. Furthermore in 3D-OSEM the lateral wall was assessed lower than in FBP, and we don't have a clear explaining for this result yet. However it has been reported that the high spatial resolution application may have the ability to separate inferior wall from adjust bowel uptake (6). Therefore other studies will be needed to assess the diagnostic value of 3D-OSEM in MPS.

The SSPAC is a method used to create an attenuation coefficient map using the sub-window set on the lower energy side than photopeak of projection data. Because the attenuation coefficient map is made by the SPECT data itself, the advantage of this method is a lack of location misregistration on the attenuation coefficient map without the need to add the radiation exposure. There are some reports that have commented on the benefits in the assessment of RCA regions using SSPAC in MPS (11, 12). Yamanouchi et al (11). reported the SSPAC's utility for 150 patients on whom MPS was conducted for the purpose of cardiac disease diagnosis, and concluded that the diagnostic value including sensitivity, specificity, accuracy, positive predictive value as well as negative predictive value had significantly improved compared with non-corrected images. Regarding SSPAC, the count elevation effect in the inferior region has already been confirmed. In our study, the effect was shown in both genders with statistical significance, however the effect was lesser than compared with FBP. Conversely, from this result it could be speculated that the risk of over-correction which we faced in the inferior wall by CT-AC could be avoided. In this study, the highest count elevation was observes in the septal region. And the accumulation value tends to become low in clinical cases. It may be due to attenuation reduction caused deep inside of the body, and the low count of this region is a common feature when compared to the 360° rotation acquisition. Regarding lateral wall especially in anterior side, although the higher counts were observed especially in FBP, it was dissolved in SSPAC and the effect also shows a significant difference statistically. As a result, SSPAC can be considered to have the benefit of reducing the proper accumulation unbalance of septal, inferior and lateral wall in FBP which sometimes misleads us into misdiagnosis. However, we should always carefully monitor septal count reduction in the apical region.

The major limitation of this study was the small number of patients. In addition, the results may be biased because the study was conducted in a single institution. The comparative analysis between SSPAC and prone image in larger studies may be effective in revealing the overall benefits of SSPAC higher.

Conclusion

With the use of GCA-9300R, the perfusion count tends to become lower in the inferior and septal area, especially in male cases. The normal perfusion count is matched with the feature of 360° rotation acquisition reported in past. When we conduct MPS using GCA-9300R, we should take care of the perfusion count reduction in the septal, lateral and apical region with 3D-OSEM, especially in male case. In combination with SSPAC, the count reduction in septal and inferior regions and the count elevation in lateral wall could be corrected, and we could get more precise image to make a more accurate diagnosis.

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Conflicts of interest

None.

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