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Effect of Noise Reduction Filters in Extracardiac Accumulation Masking Processing on Defect Score and Left Ventricular Volume

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ABSTRACT

Background: The extracardiac accumulation masking (MUS) method reduces artifacts from extracardiac accumulation by masking post-reconstruction and filtering. However, the impact of filter parameters on defect scores and cardiac function remains unclear. Thus, this study aimed to evaluate the effect of noise reduction filters in MUS on the defect score and left ventricular volume. **Methods:** To simulate the defect area, an RH-2 cardiac phantom (Kyoto Kagaku, Japan) was used with 99mTc solutions for the heart and liver. The heart-liver distance was varied (0, 1, and 2 ㎝). SPECT/CT and image reconstruction was performed using filtered back projection (FBP) with a Butterworth filter. The cut-off frequencies (0.3 to 0.7 cycles/㎝) were applied for both conventional and MUS methods. And a summed score (SS) and the left ventricular volume was employed as evaluation metrics. **Results:** SS values were more stable with the MUS methods than the conventional methods, especially at distances of 1 and 2 ㎝. Left ventricular volume increased with higher cut-off frequencies with no significant differences between MUS and conventional methods. **Conclusion:** The MUS method can reduce the impact of different cut-off frequencies on the defect score.

Keywords: Myocardial Perfusion Imaging, Butterworth Filter, Cut-Off Frequency, Left Ventricular Volume, Summed Rest Score

Introduction

Myocardial perfusion imaging (MPI) with single-photon emission computed tomography (SPECT) was used to diagnose myocardial ischemic [1]. ^{99m}Tc-Tetrofosmin, ^{99m}Tc-methoxy isobutyl isonitrile, and ^{201}TlCl are used for MPI SPECT imaging [2]. ^{99m}Tc-labeled radiopharmaceuticals imaging is superior to ^{201}TlCl imaging in terms of image quality. However, ^{99m}Tc-labeled radiopharmaceuticals are excreted via the hepatobiliary system. The artifacts caused by hepatobiliary accumulation are problematic. Accumulation in the gallbladder and liver quantitatively affects cardiac quantitative values [3]. Various solutions have been proposed to reduce the impact of artifacts on image quality, such as taking lemon juice 10 minutes after ^{99m}Tc-Tetrofosmin as lemon accelerates excretion and improves the heart/liver ratio by reducing extracardiac activity [4].

Compared to conventional methods, the extracardiac accumulation masking (MUS) method for cardiac SPECT images reportedly enhance the separation accuracy between extracardiac uptake and the myocardium and improve image stability [5]. Noise-reduction filters are applied before and after image reconstruction, followed by masking. Unlike conventional methods, the MUS approach applies masking after image reconstruction, with noise reduction filters incorporated in the process [5]. However, the impact of the noise reduction filter parameters used in the MUS method on defect scores and cardiac function parameters has not been thoroughly investigated. The noise reduction filter parameters were

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determined depending on the facility, leading to potential variability [6]. Noise reduction filters, such as the Butterworth filter, can influence image quality and diagnostic performance of myocardial SPECT depending on the processing method and parameters. Careful investigation of their impact and appropriate application is necessary [7,8].

This study evaluates the effects of noise reduction filters in extracardiac accumulation masking processing on the defect score and left ventricular volume in a myocardial phantom.

Material and Methods

1. Phantom

An RH-2 cardiac phantom (Kyoto Kagaku, Kyoto, Japan) was used. The left ventricular volume was 94.09 ㎖. The heart and liver parts were filled with 120.2 kBq/㎖ and 240.2 kBq/㎖ of ^{99m}Tc solutions. The defect area (2.3 ㎖) was simulated on the posterior wall of the left ventricle. The distance between the heart and liver was changed to 0, 1, or 2 ㎝ (Fig. 1).

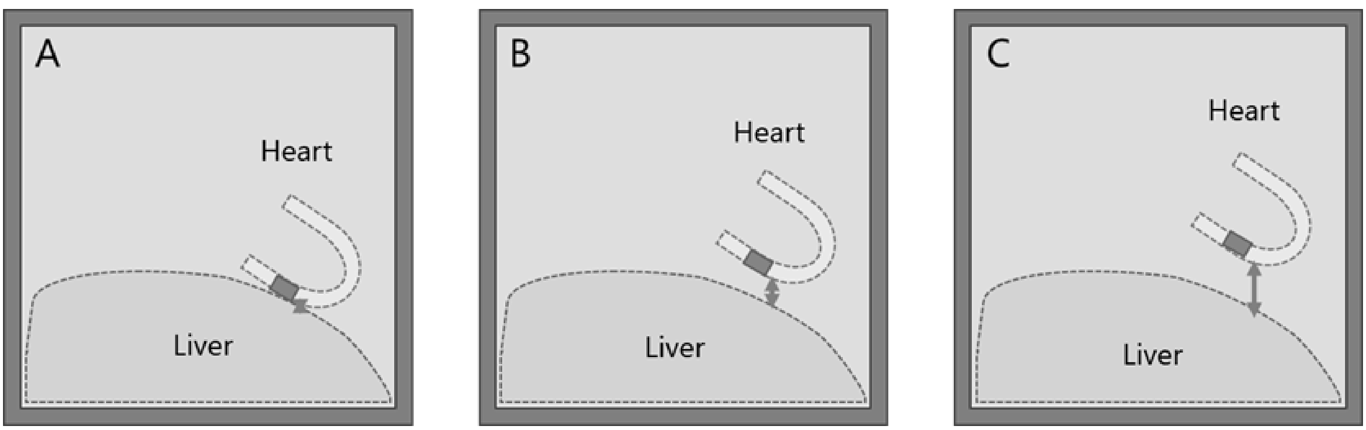

Fig. 1. The diagram of a phantom RH-2 cardiac phantom.
(A) Heart-liver distance: 0 ㎝, (B) Heart-liver distance: 1 ㎝, (C) Heart-liver distance: 2 ㎝. The defect area was set on the posterior wall of the left ventricle.

2. SPECT/CT scanner and acquisition

A dual-head SPECT/CT camera (Infinia8 Hawkeye 4; GE Healthcare, Chicago, IL, USA) was used for image acquisition. The collimator is a low-energy, high-resolution collimator. The SPECT imaging parameters were as follows: matrix, 64 × 64; step angle, 3 degrees/step, acquisition time, 20 seconds/view; energy windows, 140.0 keV ± 10% (main) and 120.0 keV ± 5% (sub); The distance from collimator to the phantom, 230 ㎜. The CT scan parameters were as follows: slice thickness, 6.1 ㎜; slice spacing, 4.42 ㎜; matrix, 512 × 512; voltage, 140 kV; current, 2.5 ㎃; Helical pitch, 1.9.

3. Image reconstruction and reformat

SPECT images were reconstructed using filtered back projection (FBP) using Xelesris 3.1 (GE Healthcare, Chicago, IL). Manual reformatting was performed after applying the Butterworth filter to both the conventional and MUS methods. MUS method applies masking after image reconstruction, with noise reduction filters incorporated in the process [5]. The process of the MUS method and conventional method are shown in Fig. 1. The cut-off frequencies were 0.3, 0.4, 0.5, 0.6, and 0.7 cycles/㎝. The order was 5.

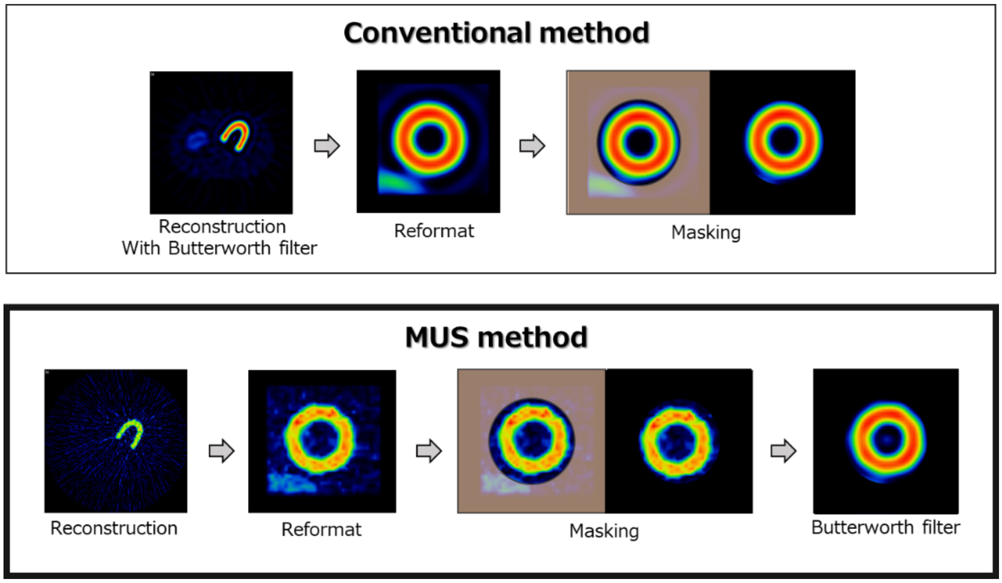

Fig. 2. The process of the MUS method and conventional method.
Reformatting, masking, and noise-reduction filtering were performed on the data, following reconstruction.

4. Data analysis

Cardio REPO software (PDR Pharma, Tokyo, Japan) calculated the Semi-Quantification and left ventricular volume. The % uptake was calculated for each of the 17 segments using a polar map. The degree of the defect area was classified automatically into a 5-point scoring grade (0, normal uptake; 1, mildly decreased uptake; 2, moderately decreased uptake; 3, severely decreased uptake; and 4, no uptake). The summed score (SS) was defined as the summed score with all semi-quantified segments. The left ventricular volume was automatically calculated using cardiac function analysis software (Cardio REPO, PDR Pharma).

Results

1. Polar map

The polar maps are shown in Fig.3. It is difficult to visualize the defect area regardless of the cut-off frequency using MUS and conventional methods at a distance of 0 ㎝ between the heart and liver. However, the visibility of the defect area was improved by increasing the cut-off frequency at a distance of 0 ㎝ between the heart and liver. The defect area size was larger using the conventional methods with increasing cut-off frequency at 1 ㎝ and 2 ㎝ distance between the heart and liver. However, there were no differences in the defect area size using MUS methods when the cut-off frequency was altered at 1 ㎝ and 2 ㎝ distance between the heart and liver.

2. Semi-Quantification

Fig. 3 A, B, C, and Table 1 shows the SS plotted versus the cut-off frequency. The SS (0 ㎝) was 22, 21, 21, 18, and 10 with conventional methods, and 21, 20, 19, 14, and 13 with MUS methods when the cut-off frequencies were 0.3, 0.4, 0.5, 0.6, and 0.7 cycles/㎝, respectively. The SS changed with varying cut-off frequencies. The heart-to-liver distance was 1 or 2 ㎝, and higher SS values were observed under conditions with a low cut-off frequency in the conventional method. However, the SS in the MUS methods was relatively stable compared to that in the conventional methods when the cut-off frequency was altered.

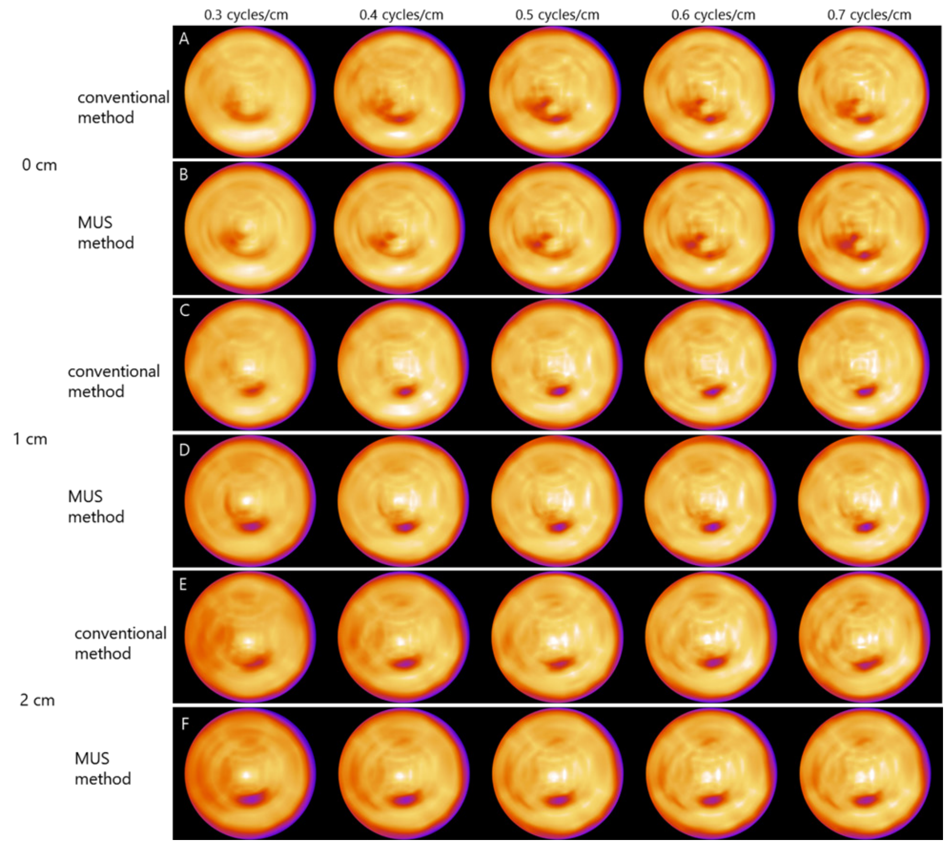

Fig. 3. The polar map with modified cut-off frequency.
(A) conventional method at 0 ㎝, (B) MUS method at 0 ㎝, (C) conventional methods at 1 ㎝, (D) MUS methods at 1 ㎝, (E) conventional method at 2 ㎝, (F) MUS method with at 2 ㎝. The visibility of the defect area was improved by increasing the cut-off frequency. However, there was no difference between conventional methods and MUS methods.

3. Left ventricular volume

Left ventricular volume with MUS methods and conventional methods are shown in Fig. 4 D, E, F, and Table 1. Left ventricular volume (0 ㎝) were 94.6 ㎖, 105.5 ㎖, 107.1 ㎖, 108.3 ㎖, 109.4 ㎖ with conventional methods, and 89.3 ㎖, 104.3 ㎖, 106.4 ㎖, 107.9 ㎖, and 109.0 ㎖ with MUS methods when the cut-off frequency was varied 0.3, 0.4, 0.5, 0.6, 0.7 cycles/㎝, respectively. The left ventricular volume increased with increasing cut-off frequency and converged over 0.6 cycles/㎝. There was no difference in the cut-off frequency between the MUS and conventional methods.

Table 1. The difference in summed score and left ventricular volume between conventional method and MUS method.

	Summed score						Left ventricular volume					
	0cm		1cm		2cm		0cm		1cm		2cm	
Cut-off frequency (cycles/cm)	MUS	conventional	MUS	conventional	MUS	conventional	MUS	conventional	MUS	conventional	MUS	conventional
0.3	21	22	7	16	6	16	89.4	94.6	85.6	91.4	85.0	88.4
0.4	20	21	9	17	8	14	104.3	105.5	101.2	96.4	95.0	101.3
0.5	19	21	9	11	10	8	106.4	107.2	110.4	105.5	101.6	101.9
0.6	14	18	9	10	10	10	107.9	108.3	110.1	109.1	101.6	103.7
0.7	13	10	9	12	12	13	109.0	109.4	109.7	109.5	107.1	107.0

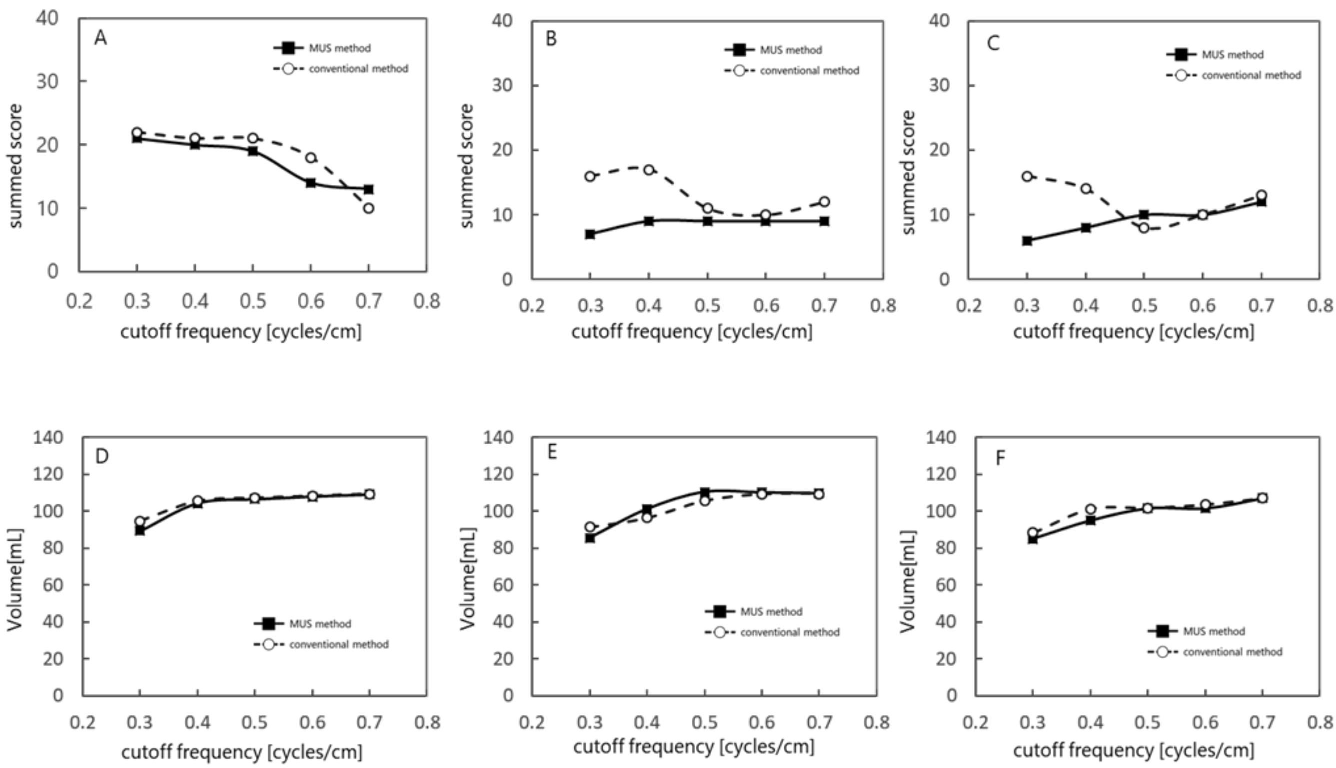

Fig. 4. The difference in SS and volume between conventional methods and MUS methods with each distance. (A) SS (Heart-liver distance: 0 ㎝), (B) SS (Heart-liver distance: 1 ㎝), (C) SS (Heart-liver distance: 2 ㎝), (D) Volume (Heart-liver distance: 0 ㎝), (E) Volume (Heart-liver distance: 1 ㎝), (F) Volume (Heart-liver distance: 2 ㎝). The SS in MUS methods were relatively stable compared to conventional methods when the cut-off frequency was altered. Moreover, there was no difference in left ventricular volume between MUS and conventional methods.

Discussion

The effect of noise reduction filters in extracardiac accumulation masking processing on the defect score and left ventricular volume with myocardial phantom was evaluated using a myocardial phantom. Variations in SS with the cut-off frequency were lower in the MUS method than the conventional method, with no difference in left ventricular volume between methods.

In cases where the heart-liver distance was 0 ㎝, the SS values changed with variations in the cut-off frequency in both the conventional and MUS methods. Lowering the cut-off frequency reduces the noise components but increases image blurring. As a result, the separation accuracy between the liver and heart changed; higher SS values were observed at higher cut-off frequencies, and lower SS values were observed at lower cut-off frequencies. The MUS method is less affected by extracardiac uptake than the conventional method using FBP; however, complete elimination of extracardiac uptake remained a challenge in a previous study [9]. Therefore, the SS values changed for both methods in this study. In contrast, extracardiac uptake can be almost eliminated in the MUS method using ordered subset expectation maximization (OS-EM) with spatial resolution correction (RR) [9]. Thus, the influence on SS values by changing the cut-off frequency on the SS values might be minimized by using OS-EM with RR.

In cases where the heart-liver distance was 1 and 2 ㎝, the SS values of the conventional method varied with changes in the cut-off frequency; however, the MUS method was only slightly affected. Sayed et al. reported that the cold contrast was reduced at a low cut-off frequency [10]. Based on this, the SS is expected to be lower at lower and higher cut-off frequencies. This trend was observed in the MUS method but not in the conventional method. This is because SS is affected not only by the cut-off value but also by extracardiac uptake in the conventional method. SS is an important value for diagnosing coronary artery disease in MPI, and the MUS method is considered one of the techniques that allows for more stable SS calculations. However, the impact of the cut-off frequency cannot be eliminated, and it is important to set appropriate parameters.

Left ventricular volume increased with increasing cut-off frequency, and there was no difference in left ventricular volume between the MUS and conventional methods. Mardanshahi AR et al. reported that end-diastolic and end-systolic volumes increased with increasing cut-off frequency using a Butterworth filter, which is in line with the findings of this study [11]. This is considered to be due to the reduction in the left ventricular volume caused by increased blurring as the cut-off frequency decreases. The volume was calculated using the endocardial surface and left ventricular valve plane [12]. Therefore, the influence of the liver, which is located outside the heart, was considered minimal. Based on these observations, it is considered that there is no difference between MUS and conventional methods.

This study had some limitations. First, the effect of the noise reduction filter was determined using only a phantom because this was a basic study. Accordingly, the effect of noise reduction filters should be investigated in future studies on clinical patients. Second, the evaluation was conducted based on a single radiopharmaceutical concentration in the liver. However, Kapur et al. reported that the heart and liver count ratio was 1.86 with MIBI and 1.72 with Tetrofismin [3]. Thus, a heart-to-liver count ratio of 2:1 was considered sufficient.

Conclusion

The effects of noise reduction filters in the extracardiac accumulation masking processing on the defect score and left ventricular volume in a myocardial phantom were evaluated. The SS in the MUS method was relatively stable compared to the conventional methods when the cut-off frequency was altered. It is possible to reduce the impact of different cut-off frequencies on the defect score using the MUS method.

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Conflicts of interest

The author declared no conflicts of interest.

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