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浅尾，喜美枝
Graduate School of Medical Sciences, Kyushu University

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ORIGINAL ARTICLE

<Original article>

The interpolated projection data estimation method improves the image quality of myocardial perfusion SPECT with a short acquisition time.

<Short title> IPDE improves SPECT MPI

Kimie Asao, BS1)2), Akihiro Takaki3), Mitsuhiro Tominaga, MD4), Masayuki Sasaki, MD, PhD1)

1) Division of Radiological Science, Department of Health Sciences, Graduate School of Medical Sciences, Kyushu University

2) Department of Radiology, Kyushu Central Hospital of the Mutual Aid Association of Public School Teachers

3) Clinical Application Technology Department, FUJIFILM RI Pharma Co., Ltd, Tokyo, Japan

5) Department of Cardiovascular Internal Medicine, Kyushu Central Hospital of the

Mutual Aid Association of Public School Teachers

Corresponding author:

Masayuki Sasaki, MD, PhD

Division of Radiological Science,

Department of Health Sciences,

Graduate School of Medical Sciences,

Kyushu University,

3-1-1 Maidashi,

Higashi-ku,

Fukuoka 812-8582, Japan

Phone : +81-92-642-6746, FAX : +81-92-642-6674

E-mail : msasaki@hs.med.kyushu-u.ac.jp

Abstract

Objective

The interpolated projection data estimation processing (IPDE) method increases the amount of projection data by interpolation of the projection data. We examined the usefulness of the IPDE method for ^{201}Tl myocardial perfusion imaging (MPI) single photon emission computed tomography (SPECT) with a short acquisition time.

Methods

Forty patients with suspected ischemic heart disease underwent stress ^{201}Tl-MPI SPECT. Both stress and delayed images were acquired by 4 cycles of 360° continuous rotation with a 90-direction setting for 14 min. The projection data used for reconstruction were 1) all cycle data (Tl-90-14min), 2) 2 cycles of data (Tl-90-7min), and 3) 2 cycles of data processed using the IPDE method (Tl-180IPDE-7min). This study compared the detection of the perfusion defect by the uptake score and the image quality of ^{201}Tl-MPI SPECT using the normalized mean square error (NMSE).

Results

The uptake score of Tl-180IPDE-7min was significantly more concordant with Tl-90-14min in comparison to the Tl-90-7min ($p<0.05$). The NMSE of the Tl-180IPDE-7 min (1.85±1.06%) was significantly lower than that of the Tl-90-7min

(2.07±1.24%) ($p<0.05$). The degree of improvement by the IPDE method was significantly greater for the delayed ^{201}Tl-MPI SPECT than for the stress ^{201}Tl-MPI SPECT ($p<0.05$).

Conclusion

The IPDE method improved the image quality and secured the diagnostic ability of ^{201}Tl-MPI SPECT for a short acquisition time. Furthermore, the IPDE method is a simple software program that does not require any expensive equipment or use advanced algorithms. These results suggest the possibility that the IPDE method can be useful as a supporting method for shortening the acquisition time of ^{201}Tl-MPI SPECT.

Key words:

myocardial perfusion, SPECT, interpolation, short acquisition time, reconstruction,

Introduction

^{201}Thallium chloride (^{201}Tl) myocardial perfusion imaging (MPI) using single photon emission computed tomography (SPECT) (^{201}Tl-MPI SPECT) is widely used to diagnose ischemic heart disease and to evaluate the extent of myocardial viability [1, 2, 3]. The physical half-life of ^{201}Tl is 73 hours, restricting the dose that can be injected. Therefore, ^{201}Tl-MPI SPECT requires 15 to 30 minutes of acquisition in order to secure a clinically sufficient image quality. During the acquisition, patients are placed in a supine position and both of their arms are kept elevated. Some elderly or severely ill patients cannot tolerate this long acquisition time.

Several methods have been proposed to shorten the acquisition time, one of which involves a 180-degree data collection procedure [4, 5]. Rotation of the gamma camera is performed from the right anterior oblique to the left posterior oblique. Several groups have proposed a shorter acquisition protocol that collects fewer angular projections and also a reduced time per projection [6, 7]. Kojima et al. proposed an off-peak window energy setting which increases the primary counts rate of ^{201}Tl, and also improves the image quality [8]. A new advanced reconstruction algorithm based on an iterative reconstruction method with resolution recovery controls the effects of noise [9, 10, 11]. These algorithms are expected to allow shorter acquisition times to be used.

A high sensitivity semi-conductor gamma camera is also expected to allow high quality images to be obtained during a short acquisition time [12]. Although these advanced technologies are expected to provide high quality images, they have not become widely distributed because they cannot be generalized to all types of cameras or institutions.

The interpolated projection data estimation processing (IPDE) method is a recently developed software program which increases the amount of projection data by interpolation of the projection data [13]. Additional projection data at the intervening angles is generated based on the assumption by the weighted average of the two adjacent projection data. The brain perfusion SPECT processed by the IPDE method had improved image quality compared to unprocessed data. Thus the IPDE method is expected to allow the possibility of shortening the acquisition time without sacrificing the image quality. Furthermore, the IPDE method is a simple software program, and does not require any expensive equipment or use advanced algorithms. The aim of this study was to examine the effect of the IPDE method for improving the image quality of MPI SPECT with a short acquisition time.

Materials and Methods

Subjects

Forty consecutive patients with suspected ischemic heart disease who underwent ^{201}Tl MPI SPECT from March to April 2010 were examined in this study. The subjects included 28 males and 12 females, ranging in age from 28 to 88 years (mean ± standard deviation (SD): 66.7±13.3 years, median age: 70 years). The clinical characteristics of the patients are provided in **Table 1**. This was a retrospective study, and the results did not influence further therapeutic decisions. This study was approved by the review board of the Ethics Committee of our institution (No. 22-148).

Data acquisition

All patients underwent both stress and delayed MPI SPECT with intravenous administration of 111MBq of ^{201}Tl during stress. The SPECT data acquisition was started at 15 minutes (stress MPI SPECT) and 4 hours (delayed MPI SPECT) after the injection, respectively. A dual-headed gamma camera (e.cam; Toshiba Medical Systems Corp., Tokyo, Japan) equipped with a low and middle energy, and general purpose (LMEGP) collimator was used for this study. The acquisition energy window was centered at 74 keV with a 27% width and at 166 keV with a 17% width. The data acquisition of both stress and delayed MPI SPECT were performed by continuous rotation of 360° for about 14 min (200 sec/cycle×4 cycles), in 90 directions over the

360° scan (sampling pitch of 4°) with a 64 × 64 matrix (a pixel size of 6.61×6.61 mm) (Tl-90-14min). The Tl-90-14min protocol was used as a standard in this study. The average count in the central slice of the vertical long axis of left ventricular myocardium from 40 cases was $8.99\times10^3\pm1.44\times10^3$counts in stress images and $4.31\times10^3\pm7.02\times10^2$ counts in delayed images.

Preparation of projection data

The projection data consisting of the first 2 cycles of the Tl-90-14min data were generated and named “Tl-90-7min”. The acquisition time of this generated data (Tl-90-7min) was 7 minutes and its sampling number was 90 directions. The IPDE method was applied to Tl-90-7min to generate interpolated data for the 90 directions between the 90-direction original projection data. In **Figure 1**, the original projection data acquired in 90 directions with a sampling pitch of 4° are shown in the upper row. In the second row, additional projection data at each intervening angle were generated using the IPDE method. For example, the data of frame #1.5, which correspond to the data at the sampling angle at # 2°, was determined by averaging the data from adjacent projections (frames #1 and #2). In the lower row, the new projection data in 180 directions with a sampling pitch of 2° were obtained. The generated data finally included 180-direction data with a 7-minute acquisition time (Tl-180IPDE-7min). The details of the IPDE method were described in a previous report [13]. The software program used for IPDE method is driven by a Windows platform.

Image reconstruction

Three projection data sets (Tl-90-14min, Tl-90-7min and Tl-180IPDE-7min) were reconstructed to obtain each transaxial image by the filter back projection (FBP) method using a ramp filter. The Butterworth filter with an order of 8 and a cutoff frequency of 0.53 cycles/cm was used as a pre-processing filter. Neither attenuation correction nor scatter correction were performed. The reconstructed SPECT images were presented in the standard tomographic fashion (short-axis, horizontal long-axis and vertical long-axis slices) encompassing the entire left ventricle.

A polar map in bull’s eye view was created for the MPI SPECT analysis using the cardioBull version 4 (FUJIFIRM RI Pharma Co., Ltd, Tokyo, Japan) which is a free software package for Windows [14]. This software program analyzes a polar map of MPI SPECT and statistically quantifies myocardial hypoperfusion. The program also performs prognostic stratification. A polar map is expressed in polar coordinates where the center is equivalent to the cardiac apex and the margin is equivalent to the base of the heart.

Detection of the decreased uptake area was analyzed by using the 17-segment model of the left ventricle recommended by the American Heart Association (**Figure 2**) [15]. The cardioBull software program automatically rated the degree of decreased uptake in each segment using a five degree score (0: normal uptake, 1: mildly reduced uptake, 2: moderately reduced uptake, 3: severely reduced uptake, and 4: no uptake) in comparison to the database of the Japanese standards for myocardial perfusion SPECT from the Japanese Society of Nuclear Medicine Working Group [16]. The scores of the 17 segments were added together to form the summed stress score (SSS) in the stress MPI SPECT and the summed rest score (SRS) in the delayed MPI SPECT. The uptake score in each segment of the Tl-90-7min and the Tl-180IPDE-7min was compared with that of the Tl-90-14min. The concordance rate in 1360 segments was calculated for both the stress and delayed MPI SPECT data of the 40 patients. The correlation of the summed score values (SSS and SRS) was compared between the Tl-90-14min and both the Tl-90-7min and the Tl-180IPDE-7min data.

Analysis of SPECT images

The image quality of MPI SPECT was evaluated using the normalized mean square error (NMSE) [17]. The NMSE values of Tl-90-7min and Tl-180IPDE-7min of all transaxial images were calculated using the Tl-90-14min as a standard image using the equation:

$$NMSE = \frac{\sum_{i=0}^{x}\sum_{j=0}^{y}\left(g(x,y)\cdot f(x,y)\right)^2}{\sum_{i=0}^{x}\sum_{j=0}^{y} f(x,y)^2}$$

standard image: $f(x,y)$, processed image: $g(x,y)$

The degree of the NMSE improvement by the IPDE method was also calculated using the equation:

$$NMSE\, improvement(\%) = \frac{\left(NMSE_{Tl-180IPDE-7\min} - NMSE_{Tl-90-7\min}\right)}{NMSE_{Tl-90-7\min}} \times 100$$

Statistical analysis

The differences in the concordance rates of the uptake scores were analyzed by the binomial test. The concordance of summed score values was examined using a Bland-Altman analysis [18]. The difference between 2 images was plotted against the difference of their scores. The difference was analyzed by a kappa analysis. The lack of agreement was estimated by the mean difference. The limits of agreement were expressed by the mean difference ± 2SD. The comparison of the NMSE values was performed using the Wilcoxon signed-rank test. The degree of NMSE improved by the

IPDE method was analyzed by the Mann-Whitney's U test. A *p*-value < 0.05 was considered to be statistically significant.

Results

The concordance rates of the uptake scores for the Tl-90-7min and Tl-180IPDE-7min in comparison to that of the Tl-90-14min are shown in **Table 2**. The concordance rate for the Tl-180IPDE-7min of 90.4% was significantly higher than that for the Tl-90-7min of 88.4% (p<0.05). A significant difference was also observed in the stress MPI SPECT (p<0.05).

The differences in the summed scores were analyzed using a Bland-Altman plot (**Figure 3**). The mean difference of the SSS from the Tl-90-14min was -0.60 for the Tl-90-7min and -0.10 for the Tl-180IPDE-7min. On the other hand, those for the SRS were -1.48 and -1.00, respectively. A kappa analysis demonstrated that the differences were not statistically significant. The range of the limits of both the SSS and SRS in the Tl-180IPDE-7min was also smaller than that of the Tl-90-7min (3.98 vs. 5.57, 10.1 vs. 11.9, respectively). The range of the limit of the SSS was also smaller than that of SRS for both the Tl-90-7min and Tl-180IPDE-7min.

The NMSE values in comparison with those of the Tl-90-14min were

2.07±1.24% for the Tl-90-7min and 1.85±1.06% for the Tl-180IPDE-7min (**Figure 4**). The NMSE for the Tl-180IPDE-7min was significantly lower than that for the Tl-90-7min (*p*<0.05). **Figure 5** shows the degree of the NMSE improvement by the IPDE method. The degree of NMSE improvement in delayed images of 0.294±0.267% was significantly greater than that in stress images, which was 0.145±0.108% (*p*<0.05).

Figure 6 shows images of a representative case of an old myocardial infarction in the inferolateral wall. The images of Tl-90-14min show a perfusion defect in segments 5, 6 and 11 and hypoperfusion in segments 4, 10 and 12. Although the images of the Tl-90-7min show an extended ischemic region, the images of the Tl-180IPDE-7min show results similar to those of the Tl-90-14min.

Discussion

This study examined the usefulness of the IPDE method for improving the image quality of ^{201}Tl-MPI SPECT with a short acquisition time. The uptake score of IPDE-processed ^{201}Tl-MPI SPECT data with half the acquisition time were more concordant with the data of the original full-length SPECT. The NMSE evaluation showed that the image quality of ^{201}Tl-MPI SPECT was significantly improved by the IPDE method when the acquisition time was short.

We examined the usefulness of the IPDE method by using the uptake score of a polar map. The concordance rate of the uptake score in each segment between the Tl-90-14min and Tl-180IPDE-7min data was significantly higher than that between the Tl-90-14min and Tl-90-7min data. This indicates that the concordance rate was improved by the IPDE method for a short scan time.

DePuey et al used an all purpose collimator to acquire more counts during a short acquisition time [7]. Although the use of an all purpose collimator allowed for the retention of sufficient image quality, the detectability of defects was 87% in stress MPI SPECT. In our study, the concordance rate in IPDE-processed MPI SPECT data was 90.4%. The IPDE method can be used in combination with a high resolution collimator and is considered to maintain its high diagnostic ability. However, the analysis of the difference of both the uptake scores and the summed scores suggested the possibility that the effect of the IPDE method was greater in cases with a low total count. Valenta et al observed a significant correlation for uptake in each segment between OSEM reconstructed full-time SPECT and a new iterative algorithm reconstructed for half-time SPECT [9]. Some reports have also suggested that there is a high concordance rate of defect scores provided by new iterative reconstruction algorithms with resolution recovery [10, 11]. Further examinations to compare the diagnostic abilities obtained using different modifications to the protocol and different instrumentation and software programs should be performed.

Generally, the image quality of MPI SPECT degrades with shortening of the scan time. Borges-Neto et al reported that the noise of SPECT with a half-time scan was 33% higher than that with a full-time scan [10]. We used the NMSE to evaluate the effect of IPDE on the improvement of the image quality. The NMSE for Tl-180IPDE-7min in our study was significantly smaller than that for Tl-90-7min. This result suggested that the IPDE-processed ^{201}Tl-MPI SPECT image for a short scan time was similar to the original full time SPECT image. Furthermore, the degree of NMSE improvement in delayed images was significantly larger than that in stress images. The effect of the IPDE method was considered to be especially remarkable in cases with a low total count. Because the IPDE method increases the projection data, the increased count of SPECT is considered to improve the image quality. Bieszk et al suggested that the image quality improved with increasing views [19].

This study had some limitations. The first is that the number of subjects examined was limited. Further examinations with a larger number of patients with ischemic heart disease will be required to clarify the clinical usefulness of the IPDE method. Second, the effect of the IPDE method may be influenced by the Butterworth filter [20]. The effect of the IPDE method in this study was relatively small in comparison with our previous study that was performed without the Butterworth filter [13]. The interaction between the IPDE method and the Butterworth filter should be examined.

The current results suggest the possibility that the IPDE method could be used as a supporting method for shortening the acquisition time of ^{201}Tl-MPI SPECT. A shorter acquisition time for ^{201}Tl-MPI SPECT would provide advantages with regard to patient comfort, and would potentially reduce motion artifacts. This technique may also offer the opportunity to reduce the dose of injected radioactivity while maintaining image quality. The software used for the IPDE method is driven by a Windows platform, making it applicable for most institutions, not requiring any other special software programs. The diagnostic ability of ^{201}Tl-MPI SPECT with the IPDE method should be further examined in a larger number of patients to clinically establish the usefulness of the IPDE method.

Conclusion

The IPDE method was considered to improve the image quality and to secure the diagnostic ability of 201Tl-MPI SPECT for a short acquisition time. Furthermore, the IPDE method is a simple software program, and does not require any expensive equipment or use advanced algorithms. Our present results suggest the possibility that the IPDE method could be useful as a supporting method for shortening the acquisition time of ^{201}Tl-MPI SPECT.

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FIGURE LEGENDS

Figure 1. A schematic illustration of the interpolated projection data estimation (IPDE) method. Upper row: original projection data in 90 directions with a sampling pitch of 4°, Middle row: generated projection data at the intervening angle obtained by averaging adjacent projections, Lower row: the final new projection data in 180 directions with a sampling pitch of 2°.

Figure 2. A schematic illustration of the 17 segment model of the myocardium used for scoring SPECT images.

Figure 3. An analysis of the concordance rate of the summed score values by Bland-Altman plots. (A) Tl-90-7min and (B) Tl-180IPDE-7min. (solid line: mean difference, dashed line: ± 2SD) The means difference in the Tl-180IPDE-7min data was closer to 0 than that of Tl-90-7min data. The 2SD of the Tl-180IPDE-7min data was smaller than that of the Tl-90-7min data. In both the Tl-90-7min and Tl-180IPDE-7min data, the 2SD of the SSS was smaller than that of the SRS.

Figure 4. The NMSE values of the Tl-90-7min and Tl-180IPDE-7min data. The Tl-90-14min data were used as the standard image. The NMSE for the Tl-180IPDE-7min data was significantly lower than that for the Tl-90-7min data ($p<0.05$).

Figure 5. The degree of NMSE improvement by the IPDE method. The degree of NMSE improvement in delayed images was significantly larger than that in stress images ($p<0.05$).

Figure 6. SPECT images of a patient with an old myocardial infarction in the inferolateral wall. The Tl-90-7min images show an extended false ischemic region (middle raw) in comparison to the Tl-90-14min images (upper raw images). The Tl-180IPDE-7min images were similar results to those of Tl-90-14min images (lower raw images).

Table 1. Patient characteristics

Age (years)	66.7±13.3
Male / Female	28/12
Final diagnoses	
OMI	6
OMI+AP	4
AP	10
HT	9
DCM	2
Normal	9

OMI, old myocardial infarction; AP, angina pectoris;

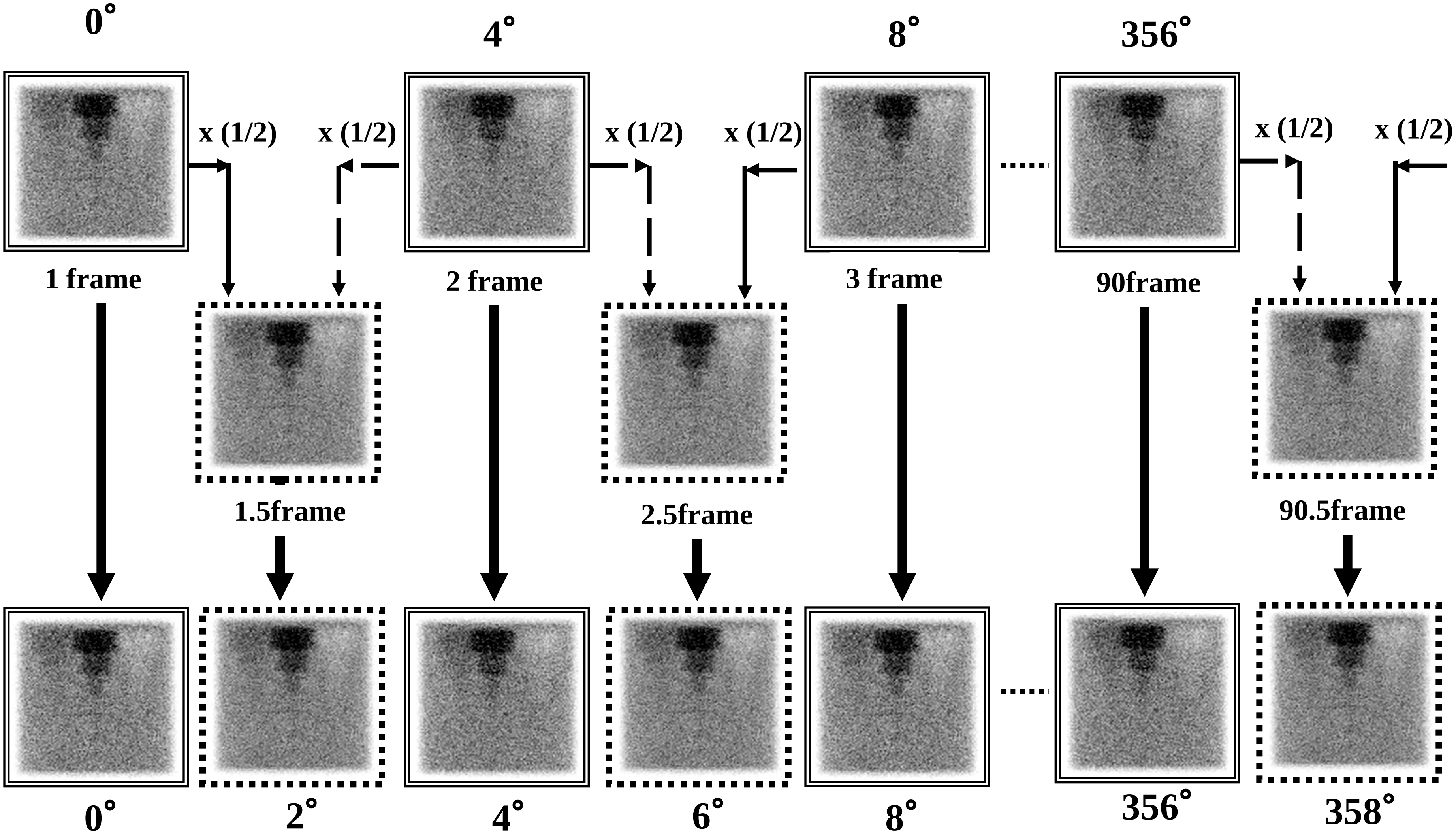
HT, hypertension; DCM, dilated cardiomyopathy

Table 2. The concordance rate of the uptake score values in comparison to those in the Tl-90-14min images.

	Tl-90-7min	Tl-180IPDE-7min
Total	88.4%*	90.4%*
Stress	90.9%*	93.2%*
Delayed	85.9%	87.5%

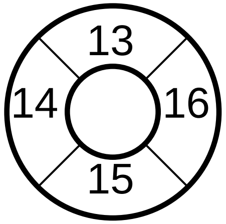
* $p<0.05$

Original projection data (sampling pitch 4°)

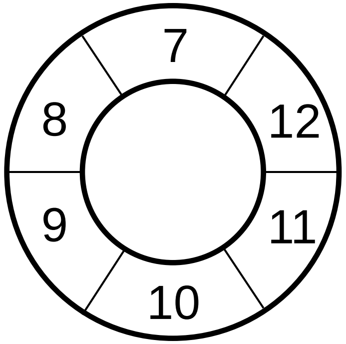


Interpolated projection data (sampling pitch 2°)

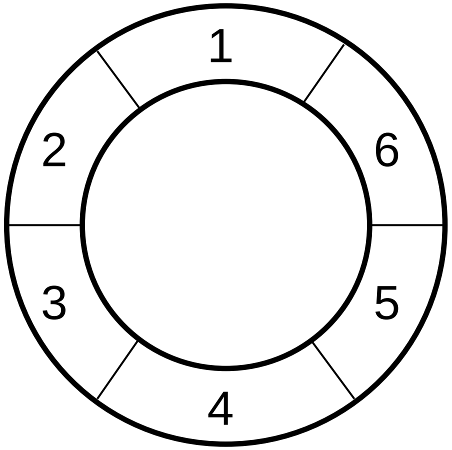
short axis
apical



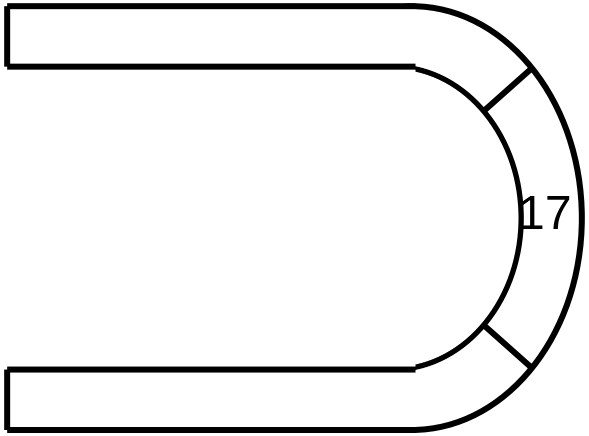
short axis
Mid



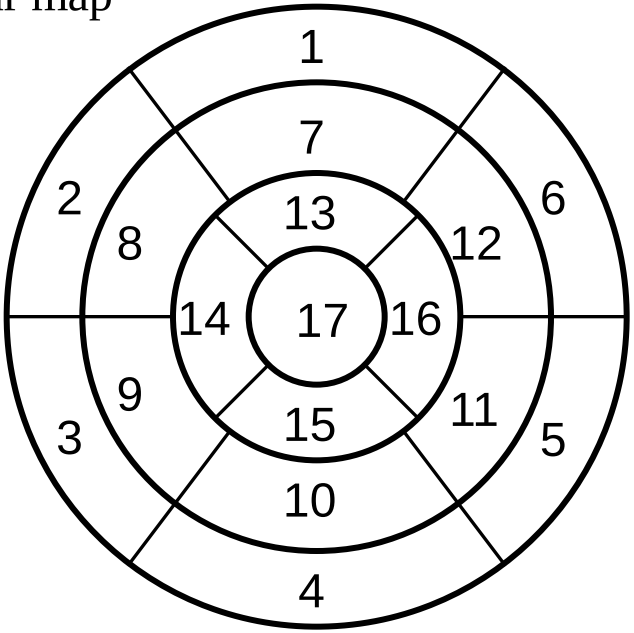
short axis
Basal

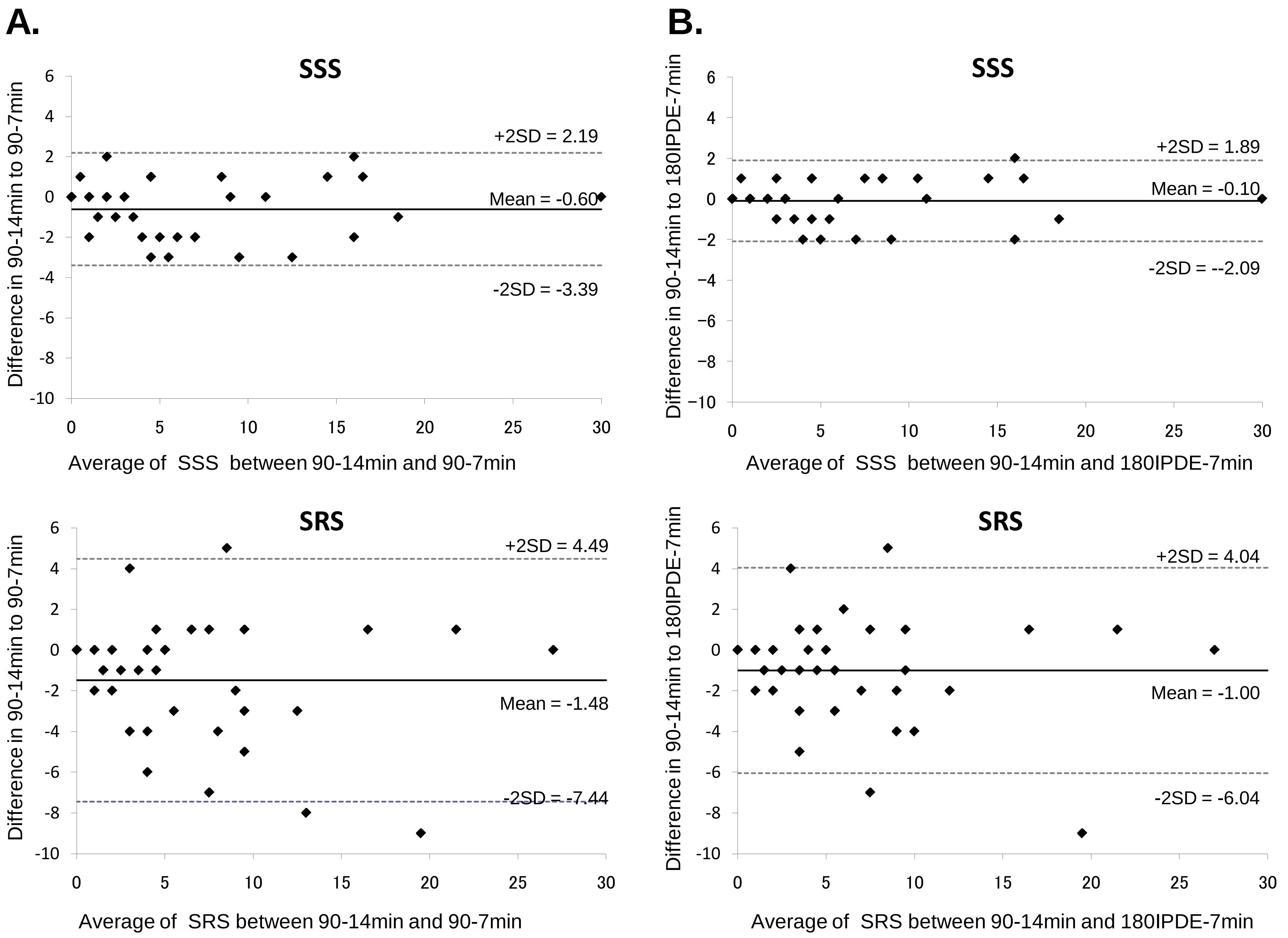


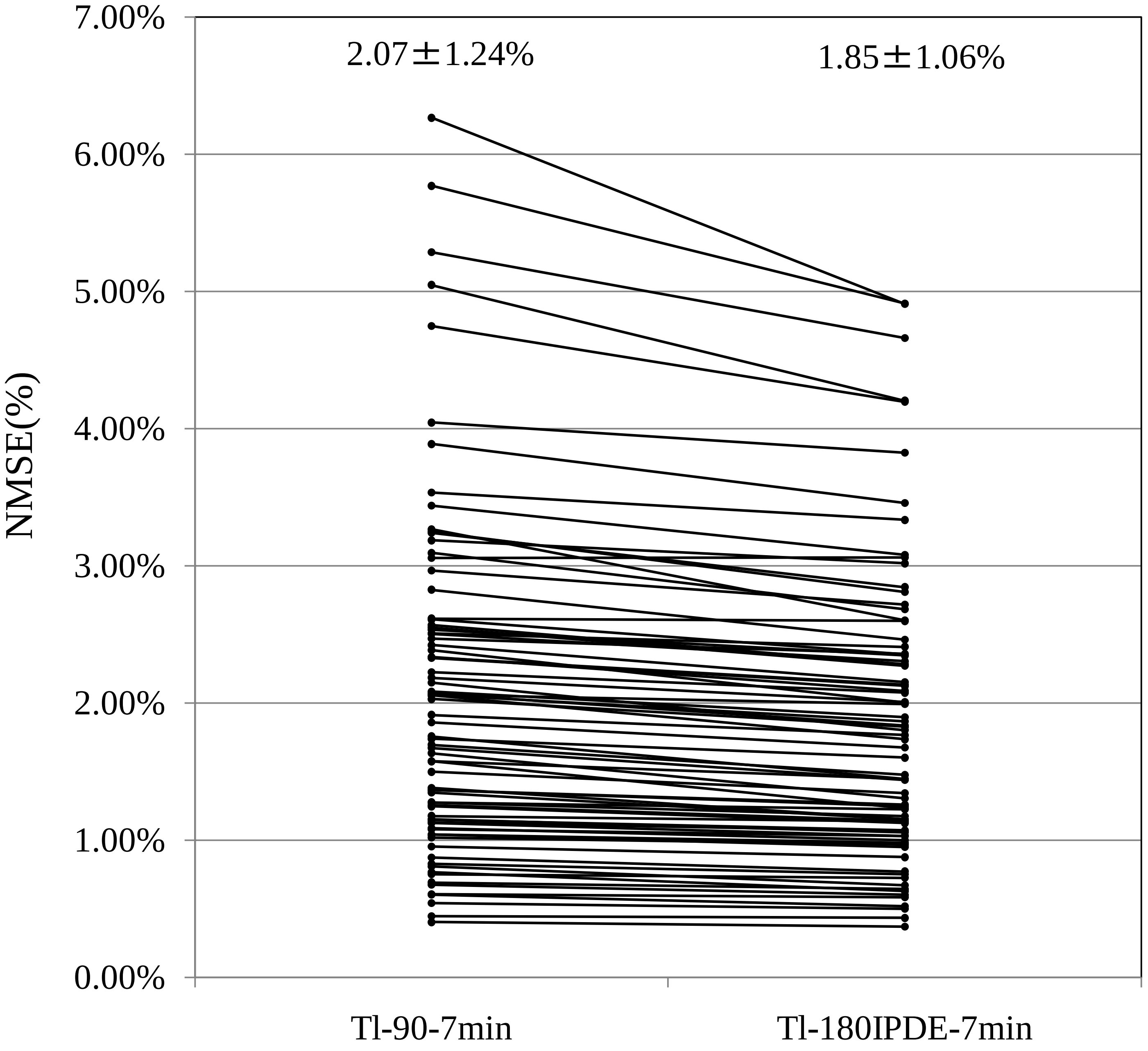
vertical long axis

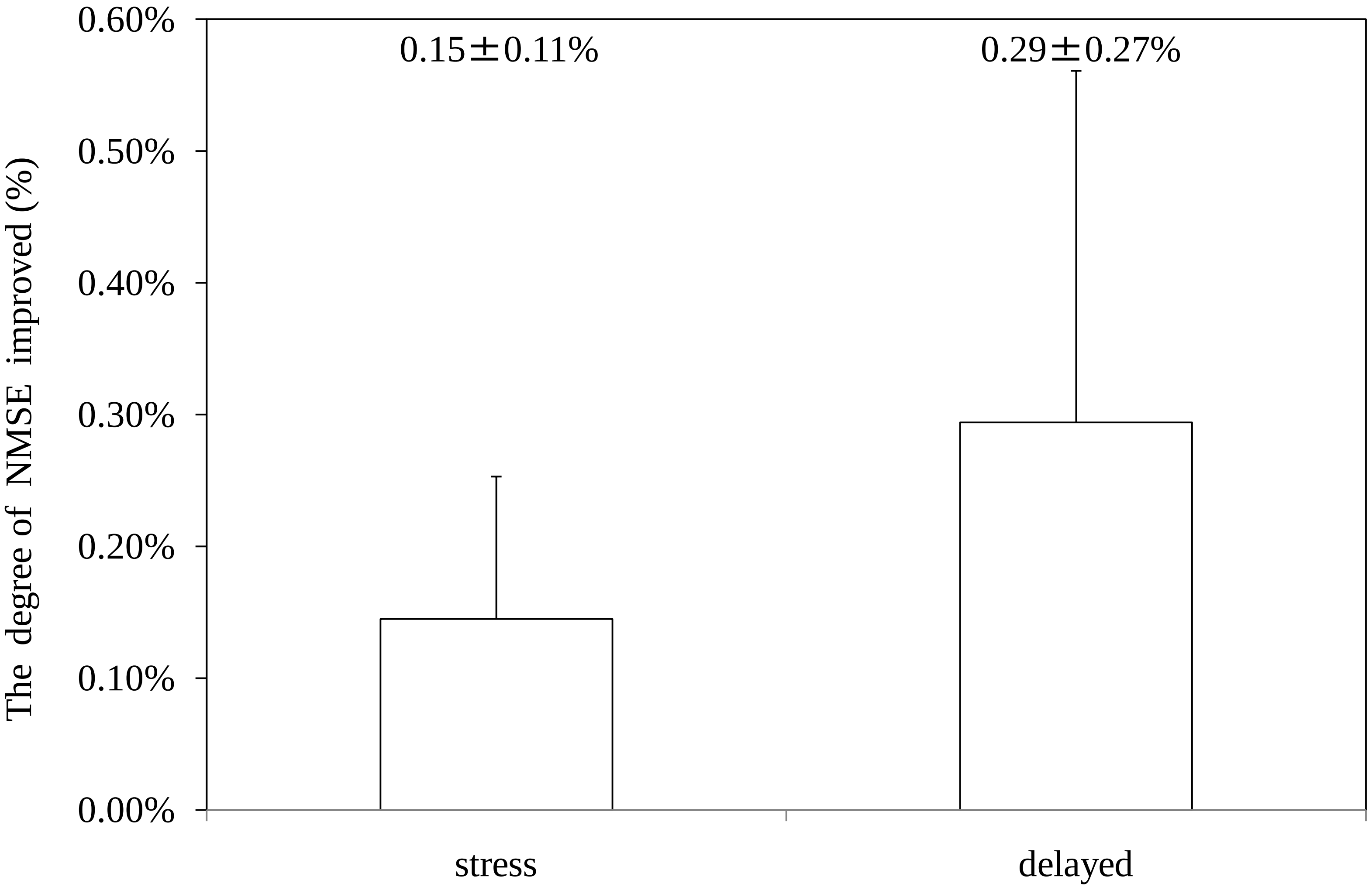


a polar map



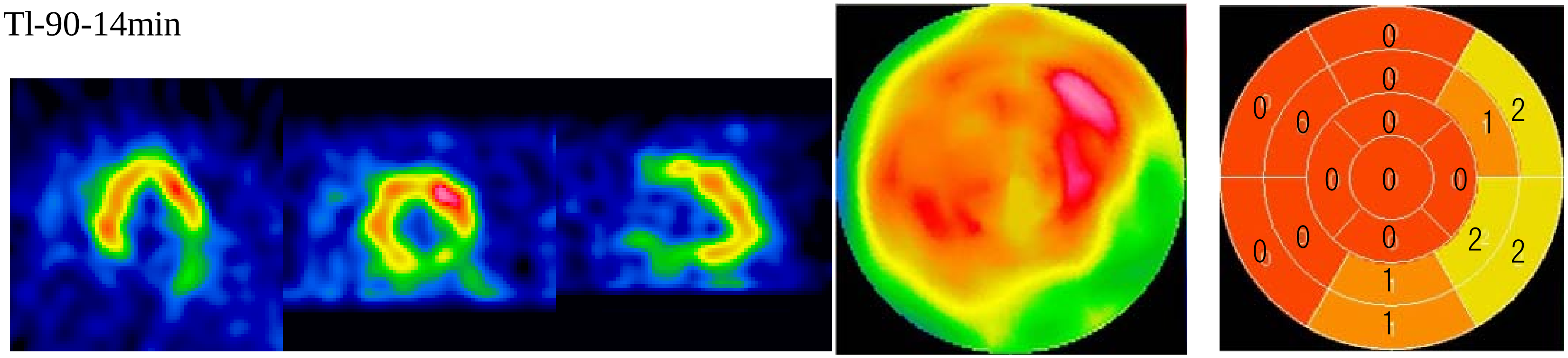

A.
SSS
Difference in 90-14min to 90-7min
Average of SSS between 90-14min and 90-7min
+2SD = 2.19
Mean = -0.60
-2SD = -3.39
SRS
Difference in 90-14min to 90-7min
Average of SRS between 90-14min and 90-7min
+2SD = 4.49
Mean = -1.48
-2SD = -7.44
B.
SSS
Difference in 90-14min to 180IPDE-7min
Average of SSS between 90-14min and 180IPDE-7min
+2SD = 1.89
Mean = -0.10
-2SD = --2.09
SRS
Difference in 90-14min to 180IPDE-7min
Average of SRS between 90-14min and 180IPDE-7min
+2SD = 4.04
Mean = -1.00
-2SD = -6.04
6
4
2
0
-2
-4
-6
-8
-10
0
5
10
15
20
25
30


7.00%
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
NMSE(%)
2.07±1.24%
1.85±1.06%
Tl-90-7min
Tl-180IPDE-7min

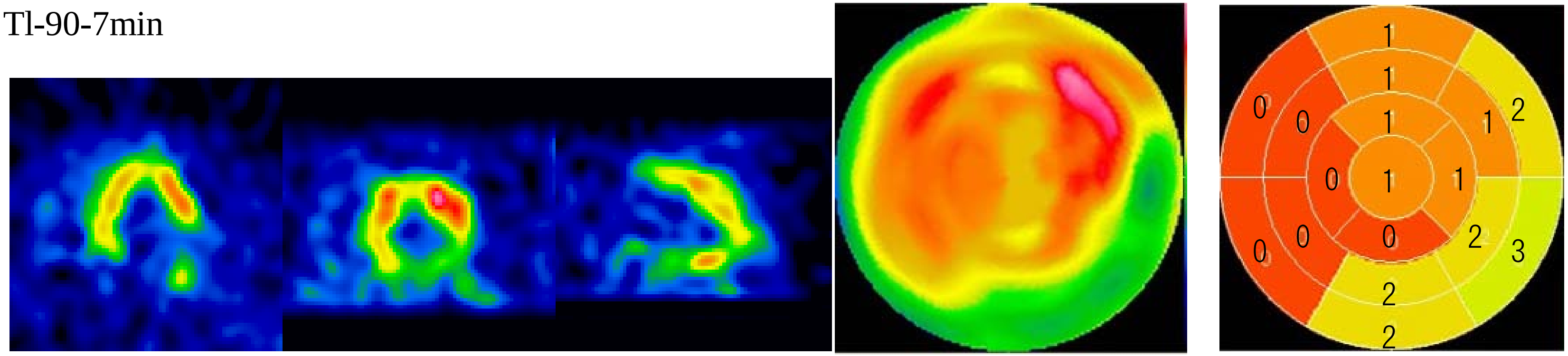


0.60%
0.50%
0.40%
0.30%
0.20%
0.10%
0.00%
The degree of NMSE improved (%)
0.15±0.11%
0.29±0.27%
stress
delayed

Tl-90-14min



Tl-90-7min



Tl-180IPDE-7min