Attenuation correction of myocardial SPECT by scatter-photopeak window method in normal subjects

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Abstract

Objective: Segmentation with scatter and photopeak window data using attenuation correction (SSPAC) method can provide a patient-specific non-uniform attenuation coefficient map only by using photopeak and scatter images without X-ray computed tomography (CT). The purpose of this study is to evaluate the performance of attenuation correction (AC) by the SSPAC method on normal myocardial perfusion database.

Methods: A total of 32 sets of exercise-rest myocardial images with Tc-99m-sestamibi were acquired in both photopeak (140keV±10%) and scatter (7% of lower side of the photopeak window) energy windows. Myocardial perfusion databases by the SSPAC method and non-AC (NC) were created from 15 female and 17 male subjects with low likelihood of cardiac disease using quantitative perfusion SPECT software (QPS). Segmental myocardial counts of a 17-segment model from these databases were compared on the basis of paired T test .

Results: AC average myocardial perfusion count was significantly higher than that in NC in the septal and inferior regions (P<0.02). On the contrary, AC average count was significantly lower in the anterolateral and apical regions (P<0.01). Coefficient variation (CV) of the AC count in the mid, apical and apex regions was lower than that of NC.

Conclusions: The SSPAC method can improve average myocardial perfusion uptake in the septal and inferior regions and provide uniform distribution of myocardial perfusion. The SSPAC method could be a practical method of attenuation correction without X-ray CT.

Keywords: Myocardial perfusion imaging, SPECT, non-X-ray based attenuation correction

Introduction

Attenuation correction (AC) with X-ray computed tomography (CT) has been sought after for reducing attenuation artifacts [1-8]. The diagnostic accuracy for detection of coronary artery disease will be increased when a myocardial perfusion SPECT (MPS) image is attenuation corrected using patient-specific non-uniform attenuation coefficient maps. Although hybrid SPECT-CT systems play an indispensable role in making non-uniform attenuation coefficient maps, they possess some technical and financial limitations. A potential misregistration between CT and MPS images may occur because of respiratory motion and patient movement [9-10]. The risk of additional radiation exposure by X-ray CT can not be avoided, and a dedicated SPECT/CT equipment is more expensive than that of conventional SPECT.

To overcome these problems, a novel AC technique called "segmentation of scatter and photopeak window data for attenuation correction (SSPAC)" method has been developed [11-12]. This new technique can make a non-uniform attenuation coefficient map, which uses only photopeak and scatter-window images obtained from SPECT acquisition. The SSPAC method may allow for correction of attenuation artifacts without X-ray CT thus avoiding the risk of additional radiation exposure.

In the present study, attenuation corrected gender-specific databases were generated to assess the effects of correction myocardial perfusion. The purpose of this study was to evaluate the standard perfusion patterns by this new approach for attenuation correction.

Materials and methods

Study population

A total of 32 subjects (17 males and 15 females, mean age 67±11 years, range 43-81) with low likelihood of cardiac disease were selected consecutively, and gated MPS was performed from August 10, 2006 to December 20, 2006. These subjects underwent exercise (n=10) or pharmacological (n=22) stress and rest studies. Indications for MPI included electrocardiographic abnormalities to rule out ischemia (n=11), screening for ischemia (n=6) and preoperative risk stratification (n=15). The possibility of ischemic heart disease was denied out by subsequent clinical studies in all patients.

Attenuation correction with SSPAC method

Patient specific AC maps were generated by the SSPAC method, which was developed at Toshiba Medical Systems, Tokyo, Japan. The SSPAC method only requires dual or triple energy window acquisition: (1) emission by 140keV±10%, (2) scatter by 7% of the lower side of the emission window (3) septal penetration by 7% of the higher side of the emission window. The procedure for AC method was as follows: First the contour maps of the body, lung, heart and liver outlines were generated from photopeak and scatter images. The body outlines were segmented from differential filtered scatter images to calculate the distance from the center of the body for each radial angle. The lung contours were determined by elliptical approximation using filtered scatter images. Segmentation of the myocardium and liver was obtained from photopeak images. The average models of

mediastinum and thoracic spine were obtained by X-ray CT and applied to generate an AC map. All contour maps were combined and segmented by three regions of bone, soft tissue and lung. An attenuation coefficient map was generated to apply attenuation coefficient values of bone, soft tissue and lung to attenuation coefficients of 0.280/cm, 0.150/cm, and 0.053/cm respectively. Finally, a Gaussian filter was applied to an attenuation coefficient map for the system resolution compensation.

Image acquisition

Stress and rest gated myocardial perfusion studies were performed during a 1-day protocol using 300MBq and 740MBq ^{99m}Tc-sestamibi respectively. MPS images were acquired by using triple-detector scintillation cameras (9300A, Toshiba Medical Systems, Tokyo, Japan) with low-energy high-resolution collimators. A total of 60 projections were obtained from a 360° circular orbit with 64×64 matrix. The pixel size was 6.4 mm. Data from emission and scatter photopeaks were collected. For gated acquisition, the division of the RR interval was 16 frames.

Data processing and analysis

The MPS reconstruction was performed with a GMS-7700R workstation (Toshiba Medical Systems) for both AC and non-attenuation correction (NC) images. Scatter correction was performed using scatter data obtained from the lower side of the main photopeak window. The AC images were reconstructed by an ordered subsets-expectation maximization algorithm with 4 iterations and 10 subsets using the attenuation coefficient map. The NC images

were also reconstructed using the same condition. Reconstructed short-axis images for AC and NC were analyzed with a quantitative perfusion SPECT and gated SPECT software (QPS/QGS, Cedars-Sinai Medical Center, Los Angeles, CA, USA). A QPS software algorithm was used to generate perfusion polar maps of 17 segments. AC and NC databases were calculated on the basis of the QPS software for both genders. Ejection fraction (EF), end-diastolic volume (EDV) and end-systolic volume (EDV) were obtained form QGS analysis.

Statistical analysis

Segmental values of the databases were expressed as the average and standard deviation, which were calculated by QPS software. A paired t test was used to compare differences in the databases for AC and NC. Since CV values were calculated to compare the uniformity of perfusion between AC and NC, differences were also assessed by a paired t test. All statistical tests were two-tailed, and a P value of less than 0.05 was considered to be significant.

Results

Left ventricular function

EF, EDV and ESV values derived from normal subjects were 70.9±7.7%, 62.1±13.7 ml, 18.8±8.3 ml for females and 64.9±9.1%, 81.8±17.8 ml, 29.1±9.9 ml for males, respectively (p=0.056, 0.002 and 0.004).

Statistical differences in database analysis

Averaged perfusion polar maps are shown in Figure 1, and calculated segmental

average and standard deviation values in 17-segment models for stress, and rest conditions are shown in Table 1. The attenuation corrected polar maps demonstrated homogeneous count distribution when the anterior and inferior counts were compared (Figure 1). Especially in the mid anteroseptal, inferoseptal and inferior segments, attenuation corrected myocardial perfusion counts were significantly higher than that of the NC (p=<0.0001, 0.0002 and 0.0003, respectively). Although the whole regions of myocardial were corrected by the SSPAC method, the segmental average value in the mid anterolateral segment showed a lower value using AC in comparison to NC (p<0.0001). Furthermore, apical thinning at the apex segment was demonstrated after AC, and the attenuation corrected average value in the apex showed a lower value (p≤0.0128). Paired *t* test results for females versus males and AC versus NC are shown in Table 2. Regarding gender differences, the mid and apical inferior regions showed lower p values with both AC and NC. Nevertheless, segmental p values differed significantly in the mid inferoseptal during rest condition and mid inferolateral during stress condition. When comparing AC and NC, the mid-anteroseptal, inferoseptal inferior and anterolateral segments showed significanty higher values in all cases.

Coefficient of variation values analysis

Calculated CV values in the mid, apical and apex regions are shown in Figure 2. Attenuation corrected CV values showed a lower variation in both genders; the mean ± SD values for females with AC and NC for stress and rest were 6.1±1.1%, 5.8±1.5%,7.0±2.4% and 7.2±2.6%, respectively, and for males, these values were 7.2±1.7%, 6.8±1.3%,9.3±1.7% and 9.8±1.4% respectively. There were statistically significant differences between AC and NC values in males (p=0.04).
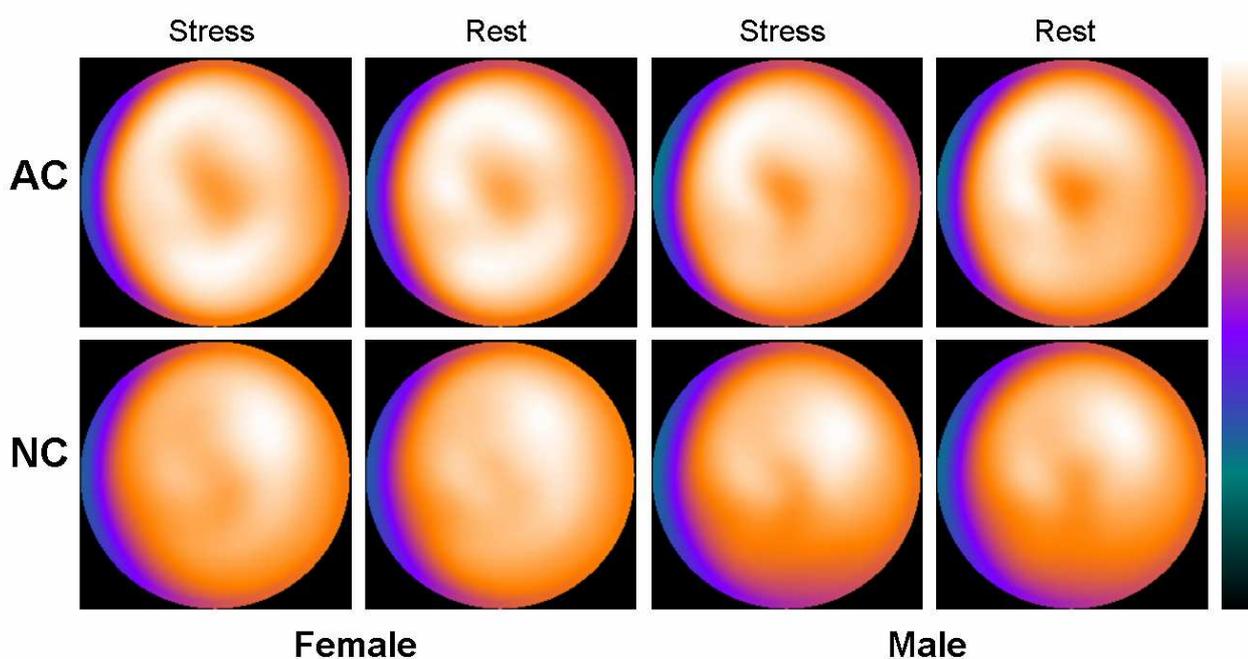

Fig. 1 Comparison of the average polar maps for AC and NC in both genders. The differences in the septal and inferior counts between AC and NC are shown.

Table 1　　Segmental average and standard deviation values in the polar maps with AC and NC

	AC				NC			
	Stress		Rest		Stress		Rest	
	Female	Male	Female	Male	Female	Male	Female	Male
Basal-A	66 ± 7	66 ± 7	73 ± 5	67 ± 7	70 ± 7	65 ± 6	72 ± 5	65 ± 6
Basal-AS	57 ± 8	56 ± 9	62 ± 8	56 ± 9	57 ± 8	53 ± 8	59 ± 6	53 ± 8
Basal-IS	62 ± 7	64 ± 9	65 ± 8	63 ± 7	58 ± 7	54 ± 7	57 ± 8	54 ± 5
Basal-I	71 ± 7	68 ± 7	75 ± 6	68 ± 6	67 ± 7	59 ± 5	66 ± 7	59 ± 5
Basal-IL	62 ± 4	61 ± 5	66 ± 5	62 ± 6	68 ± 3	64 ± 5	68 ± 5	64 ± 5
Basal-AL	58 ± 3	58 ± 6	62 ± 4	59 ± 6	70 ± 4	66 ± 5	71 ± 3	66 ± 5
Mid-A	91 ± 5	92 ± 4	93 ± 4	92 ± 5	89 ± 5	88 ± 5	89 ± 3	86 ± 5
Mid-AS	86 ± 6	88 ± 6	89 ± 4	88 ± 5	81 ± 4	79 ± 5	81 ± 4	79 ± 5
Mid-IS	83 ± 5	84 ± 5	87 ± 5	83 ± 4	76 ± 6	72 ± 5	75 ± 7	71 ± 4
Mid-I	90 ± 5	83 ± 7	93 ± 4	83 ± 6	83 ± 7	73 ± 4	82 ± 7	71 ± 4
Mid-IL	83 ± 5	80 ± 6	87 ± 5	81 ± 5	87 ± 3	82 ± 4	87 ± 4	81 ± 3
Mid-AL	83 ± 4	84 ± 6	87 ± 5	85 ± 5	93 ± 3	93 ± 3	95 ± 1	92 ± 3
Apical-A	87 ± 5	87 ± 3	87 ± 4	89 ± 4	90 ± 3	89 ± 4	89 ± 3	90 ± 5
Apical-S	88 ± 4	90 ± 4	89 ± 3	89 ± 4	87 ± 4	86 ± 5	85 ± 5	85 ± 4
Apical-I	87 ± 4	83 ± 4	88 ± 4	83 ± 4	85 ± 4	78 ± 4	82 ± 6	77 ± 4
Apical-L	85 ± 4	82 ± 3	86 ± 5	85 ± 3	92 ± 3	89 ± 3	91 ± 4	90 ± 4
Apex	80 ± 5	77 ± 6	80 ± 5	79 ± 5	87 ± 3	83 ± 4	85 ± 5	84 ± 5

A:anterior,AS:anteroseptal,IS:inferoseptal,I:inferior,IL:inferolateral,AL:anterolateral,A:Antorior

Table 2 Comparison of gender differences in AC and NC, and attenuation differences.

|	P values for Female versus Male				P values for AC versus NC			
	AC		NC		Stress		Rest	
	Stress	Rest	Stress	Rest	Female	Male	Female	Male
Basal-A	ns	0.0107	ns	0.0051	ns	ns	ns	0.0038
Basal-AS	ns	0.0471	ns	ns	ns	0.0145	0.0227	0.0028
Basal-IS	ns	ns	ns	ns	0.0052	<0.0001	<0.0001	<0.0001
Basal-I	ns	0.0037	0.0108	0.0012	0.0023	<0.0001	<0.0001	<0.0001
Basal-IL	ns	ns	0.0450	0.0257	<0.0001	0.0083	ns	ns
Basal-AL	ns	ns	ns	0.0080	<0.0001	<0.0001	<0.0001	<0.0001
Mid-A	ns	ns	ns	ns	ns	0.0023	0.0082	<0.0001
Mid-AS	ns	ns	ns	ns	<0.0001	<0.0001	<0.0001	<0.0001
Mid-IS	ns	ns	ns	0.0281	0.0002	<0.0001	<0.0001	<0.0001
Mid-I	0.0147	<0.0001	0.0001	<0.0001	0.0003	<0.0001	<0.0001	<0.0001
Mid-IL	ns	0.0022	0.0050	0.0020	0.0031	ns	ns	ns
Mid-AL	ns	ns	ns	ns	<0.0001	<0.0001	<0.0001	<0.0001
Apical-A	ns	ns	ns	ns	0.0120	ns	ns	ns
Apical-S	ns	ns	ns	ns	ns	0.0082	0.0294	0.0005
Apical-I	0.0353	0.0018	0.0005	0.0007	ns	0.0058	0.0019	<0.0001
Apical-L	ns	ns	ns	ns	0.0014	<0.0001	0.0037	<0.0001
Apex	ns	ns	ns	ns	0.0005	0.0024	0.0128	0.0012
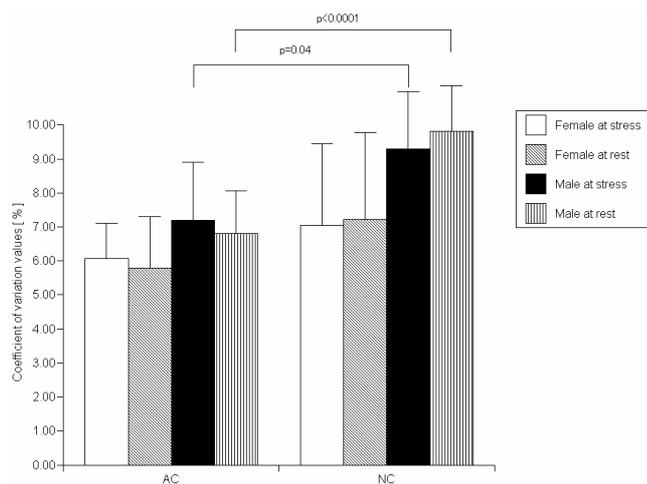
Fig. 2 The coefficient of variation (CV) values in the mid, apical and apex regions

Discussion

The SSPAC method could reduce attenuation artifacts and changed calculated segmental average values of myocardial counts in comparison with NC databases. Attenuation corrected myocardial perfusion counts were more homogeneous than NC images and the anteroseptal, inferoseptal and inferior counts were increased. Moreover, attenuation corrected databases should be created for quantitative analysis of AC images when the SSPAC method is applied to clinical uses.

MPS images frequently showed attenuation artifacts in males and females due to attenuation from diaphragm and beast. There were non-attenuation-corrected normal databases for the Japanese population in which the polar maps showed a lower count distribution in the inferior region in males. Most of the female subjects did not show a significant lower count in the anterior segment. Nakajima et al. reported that differences in sex were significant in the mid- and apical inferior segments, showing lower values in men.

Moreover, there were no significant differences in the anterior segments between genders [13]. This finding shows that the body habitus is more homogeneous in eastern Asian females and males than in European and American populations. In attenuation corrected databases, attenuation artifacts in the inferior segment were corrected in males, and the count distribution in each polar map was more homogeneous in both genders. An X-ray based AC study report also showed that attenuation corrected polar maps increased global uniformity of the count distribution [4].

A major problem is that attenuation corrected count distribution in the apex region sometimes shows a moderate defect. This apical thinning is a well known phenomenon when using the X-ray based AC method [14, 15]. This phenomenon may induce false-positive perfusion defects and may reduce the specificity in a normal perfusion. In the case of the SSPAC method, similar phenomenons have also occurred. Our previous studies have demonstrated that attenuation coefficient maps obtained from SSPAC method and transmission CT showed the similar segmentation of heart, liver, and torso [11, 12]. Therefore, if co-registarion with attenuation coefficient maps and MPS images were correctly performed, similar results might be anticipated by both SSPAC and X ray CT based AC methods.

Some reports evaluated the apical thinning in phantom and clinical studies by AC [8, 14]. In the phantom study, phantom sizes, breast tissues and reconstruction parameters were thought to be responsible for apical thinning, whereas apical thinning was a consistent finding independent on gender or

body habitus in the clinical study. Therefore, variability in the apical segment may be affected by increasing counts in the inferoseptal regions in comparison with the apical region in addition to apical wall motion in clinical study.

Considering that the count distributions differed between AC and NC databases, AC-specific database should be created in clinical practice. Count distribution between AC and NC differed between stress and rest conditions for both gender. A X-ray CT based AC study showed that gender differences were not statistically significant after AC [4]. Although quantitative analysis of myocardial perfusion required gender-specific databases, single attenuation corrected databases independent on genders would be convenient.

This study has several limitations. CT image resolution is better than that of MPS image for generating an attenuation coefficient map. Since the body contours were obtained from differential filtered scatter image, information of breast tissues was not precisely traced. The effect of dense breasts in the anterior wall should be evaluated in further clinical studies. Thus, improvement of the algorithm for detecting a body contour of breast would be required. However, Wolak et al. reported that there are no significant diagnostic differences with and without AC in women [16]. Since the diagnostic difference between SSPAC and SPECT-CT methods has not been examined, further investigation is required to evaluate the diagnostic efficacy in large numbers of patients with coronary artery disease.

Conclusion

Attenuation corrected myocardial perfusion SPECT images could be obtained without X-ray CT data. Significant segmental differences were observed in some regions between AC and NC polar maps. Since myocardial perfusion became homogeneous in the mid, apical and apex regions in the normal subjects study, attenuation corrected normal database should be generated for clinical practice. Further studies in patients with coronary artery disease should be indicated to evaluate the clinical efficacy of the SSPAC method.

Acknowledgement

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