Original article

The Value of Attenuation Correction in Hybrid Cardiac SPECT/CT on Inferior Wall According to Body Mass Index

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Abstract

The purpose of this study was to evaluate the diagnostic value of attenuation-corrected single photon emission computed tomography (SPECT) myocardial perfusion imaging (MPI) on the inferior wall compared to uncorrected (NC) SPECT MPI between obese and nonobese patients. A total of 157 consecutive patients (122 males and 35 females, with median age: 57.4 ± 11 years) who underwent AC technetium 99m-methoxyisobutylisonitrile (AC Tc99m-sestamibi) SPECT MPI were included to the study. A hybrid SPECT and transmission computed tomography (CT) system was used for the diagnosis with 1-day protocol, and stress imaging was performed first. During attenuation correction (AC) processing on a Xeleris Workstation using Myovation cardiac software with ordered subset expectation maximization (OSEM), iterative reconstruction with attenuation correction (IRAC) and NC images filtered back projection (FBP) were used. For statistical purposes, $P < 0.05$ was considered significant. This study included 73 patients with body mass index (BMI) <30 and 84 patients with BMI ≥ 30. In patients with higher BMI, increased amount of both visual and semiquantitative attenuation of the inferior wall was detected. IRAC reconstruction corrects the diaphragm attenuation of the inferior wall better than FBP. AC with OSEM iterative reconstruction significantly improves the diagnostic value of stress-only SPECT MPI in patients with normal weight and those who are obese, but the improvements are significantly greater in obese patients. Stress-only SPECT imaging with AC provides shorter and lower radiation exposure.

Keywords: Body mass index, computed tomography-based attenuation correction, follow-up, hybrid cardiac single photon emission computed tomography/CT, inferior wall

Introduction

Myocardial perfusion imaging (MPI) with single photon emission computed tomography (SPECT) is widely regarded as a clinically useful noninvasive imaging modality for the diagnosis, risk stratification, prognosis, and management of patients with coronary artery disease (CAD).[1-3] However, variable soft-tissue attenuations may cause attenuation artifacts that lower the accuracy and reduce the specificity of MPI.[4,5] Attenuation artifacts involving the inferior wall are frequently seen in men due to attenuation by the subdiaphragmatic structures and obesity, and in females due to only obesity. Thus, various techniques including electrocardiography (ECG) gating, prone imaging, and attenuation correction (AC) have been developed to improve specificity and to recompense this inadequacy.[6-8]

In recent years, the development of hybrid SPECT and transmission computed tomography (CT) devices enabled CT AC assessments to be done more accurately. This method has increased diagnostic accuracy compared to MPI or ECG-gating MPI method.[9,10]

We hypothesized that by using iterative reconstruction stress SPECT/CT AC, we may differentiate myocardial ischemia from diaphragm attenuation. Furthermore, with this technique we may eliminate subsequent rest imaging that would reduce radiation dose, imaging time, radiopharmaceutical doses, and may prevent unnecessary cardiac catheterizations.

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The purpose of this study was to compare the accuracy of attenuation-corrected SPECT/CT on the inferior wall with uncorrected (NC) SPECT between obese and nonobese patients.

Patients and Methods

Those patients with suspected CAD who were referred for CT-based AC technetium 99m-methoxyisobutylisonitrile (Tc99m-sestamibi) SPECT MPI were included in the study at the Department of Nuclear Medicine of Okmeydani Training and Research Hospital, Istanbul, Turkey between July 2010 and March 2011.

The study population consisted of 157 patients (122 males and 35 females, with mean age: 57.4 ± 11 years). The inclusion criteria involved patients with normal perfusion and left ventricular function, and those with no known CAD. The exclusion criteria were patients who had prior coronary artery bypass surgery, percutaneous coronary intervention, or prior myocardial infarction before stress imaging.

Body mass index (BMI) was calculated as weight (in kg) divided by height (in m^2), i.e., kg/m^2. The patients were classified as nonobese (BMI <30) or obese (BMI ≥30) in accordance with the World Health Organization.

Exercise stress test using a treadmill

The exercise stress test using a treadmill was performed according to the modified Bruce protocol (two stages of 2.7 km/h with 0% and 5% grades, respectively, followed by the standard Bruce protocol).[11] A minimum of 85% maximum predicted heart rate or until the patient has ECG evidence of ischemia (ST segment depression) or becomes symptom-limited. At peak stress, the radiotracer was injected intravenously and exercise was continued for an additional 60 s.

Pharmacological (dipyridamole) stress testing

The patients were instructed to avoid methylxanthine derivatives the day before the study. They underwent infusion of dipyridamole (0.56 mg/kg of intravenous dipyridamole for 4 min). The tracer was injected between 3 min and 5 min after the completion of dipyridamole infusion. During the test, ECG, blood pressure, and heart rate were continuously monitored.

MPI

The one day Tc99m-methoxyisobutylisonitrile (Tc99m-sestamibi) protocol was used and stress imaging was performed first. Stress imaging was started 45-60 min after tracer administration (8-12 mCi Tc99m-sestamibi). AC during stress MPI was routinely acquired on all the patients with CT. Rest imaging started 45-60 min after tracer administration (24-36 mCi Tc99m-sestamibi). It was not applied to those with normal stress images.

SPECT/CT protocol

A hybrid SPECT/CT system was used for the diagnosis. Gated SPECT (GSPECT) with CT-based AC was performed using a hybrid dual-head gamma camera (Infinia Hawkeye 4; General Electric Medical Systems, Milwaukee, WI, USA) equipped with high-resolution collimators. These cameras obtain data from a 45°-right anterior oblique (RAO) projection to a 45°-left posterior oblique (LPO) projection. The protocol included a 64 × 64 matrix, 32 projections, 50-s projection, and 16 frames/cycle used in association with a 15% window centered on the 140 keV photopeak of Tc-99m-labeled radiopharmaceuticals. At the end of each acquisition, a low-dose CT scan (140 kVp and 2.5 mA) of the chest was performed in order to obtain attenuation maps automatically applied by the processing software to correct the emission data.

During AC processing on a Xeleris Workstation using Myovation cardiac software with ordered subset expectation maximization (OSEM) (Infinia Hawkeye 4; General Electric Medical Systems, Milwaukee, WI), iterative reconstruction attenuation correction (IRAC) and NC images filtered back projection (FBP) were used. SPECT studies were evaluated visually and semiquantitatively.

We defined "normal" as per the following parameters: Myocardial perfusion that appears visually homogeneous, normal cavity size, and the ejection fraction ≥50% with normal left ventricular function regional wall motion; quantitative analysis shows no perfusion defect and with CT-based AC, [OSEM with CT-based AC (IRAC)] the inferior wall perfusion was normal.

Follow-up

Telephone interviews were conducted, hospital charts were reviewed, and primary physicians were contacted for confirmation. The mean follow-up was 46 ± 2 months.

Radiotion dosimetry

The average effective dose due to the radiation produced by the Hawkeye camera was 0.9 mSv for a chest scan, in addition to the 3 mSv effective dose from a standard injection of stress Tc99m-sestamibi for MPI [Table 1].[10-12]

Statistical analysis

The data were analyzed by the software program SPSS 10.0 version (Statistical Package for Social Sciences for Windows, Chicago, IL, USA). During data analysis, descriptive statistics, mean, standard deviation,

frequency, percentage, and minimum and maximum predicted heart rate were used.

The differences were assessed applying the Student's *t*-test and the relationships were analyzed by Spearman's rank correlation coefficient and binary logistic regression analysis. The results in a 95% confidence interval and $P < 0.05$ was considered statistically significant.

Ethics

The study was approved by the Local Research Ethics Committee. Informed consent was obtained from all the participating patients.

Results

This study included 73 patients with BMI values <30 kg/m^2 (nonobese group) and 84 patients with BMI values 30 kg/m^2 or greater (obese group). The mean weight of the patients was 84 ± 15 kg (range: 53-150 kg); the BMI averaged 30.2 ± 4.7 (range: 18.9-51.9) in all the groups [Table 2]. Both the images were reconstructed by FBP and OSEM; all the studies were evaluated in MPI. The AC images were processed using the OSEM iterative algoritm on the workstation. The FBP image reconstruction was utilized to process the NC images.

In patients with higher BMI (BMI ≥30), increased amount of both visual and quantitative attenuation of the inferior wall was detected. Therefore, semiquantitative results of both IRAC and FBP of the reconstruction techniques for the inferior wall were compared [Table 3].

Inferior wall defects in IRAC images were detected to be significantly lower than that of the FBP images. Diaphragm attenuation of the inferior wall with IRAC reconstruction corrects visual, and the semiquantitative results were better than that of FBP [Figure 1].

Furthermore, the BMI values were compared with the values of AC (IRAC) and NC (FBP) in myocardial perfusion images. Statistically significant differences were found in the subjective image, reconstructed between FBC and IRAC in obese and nonobese patients ($P < 0.05$) [Table 3]. Thus, CT-based iterative reconstruction images were markedly improved in the diaphragmatic attenuation on the inferior wall of all the patients.

While BMI increases, FBP, IRAC, and IRNC decreases or while BMI decreases, FBP, IRAC, and IRNC increases. Significant correlation was found for the differences between NC and corrected measurements ($P < 0.05$).

In addition, there were no differences in the subjective image quality between reconstructed images with

Table 1: MPI dosimetry data

Radiopharmaceutical	Largest radiation dose		Effective dose		Administrated activity	
	mGy/Bq	rad/mCi	mSv/MBq	rem/mCi	MBq	mCi
Tc99m-sestamibi, stress	0.039	0.14	0.009	0.033	296-444	8-12
Tc99m-sestamibi, rest	0.033	0.12	0.0079	0.029	888-1,332	24-36

MPI: Myocardial perfusion imaging

Table 2: Characteristics of study population

	Number of patients	Percent
Male	122	77.7
Female	35	22.3
Age (years)	57.4	
BMI<30	73	46.5
BMI≥30	84	53.5

BMI: Body mass index

Table 3: Results of semiquantitative measurement of IRAC, FBP, and IRNC

	BMI		*P*
	<30	≥30	
FBP	327.51	256.25 ↓	0.0004
IRAC	1066.45	959.08 ↓	0.0702
IRNC	333.48	259.85 ↓	0.0004

BMI: Body mass index; FBP: Filtered back projection; IRAC: Iterative reconstruction with attenuation correction; IRNC: Iterative reconstruction nonattenuation corrected

that of FBP and IRNC. There were no statistically significant differences between reconstructed images of FBP and IRNC. However, averages of FBP and IRNC measurement in patients with BMI values 30 kg/m^2 or greater were less than that of patients with BMI < 30, which was statistically significant ($P < 0.05$).

We compared stress MPI in patients according to BMI without (FBP and IRNC) and with CT-based AC (IRAC) reconstructed images and found statistically significant differences in the inferior wall images reconstructed between FBC and IRAC.

During mean follow-up of 56 ± 2 months, there were three noncardiac deaths. Two patients died from cerebrovascular accident and one from renal cancer (0.02%). There were no cardiac deaths and three cases of nonfatal myocardial infarction (0.02%) were observed.

Discussion

Soft tissue artifacts increase the number of false positive scan interpretations and lower the specificity of stress perfusion imaging. Men are more likely to have inferior wall defects caused by high diaphragms. MPI specificity is known to be reduced by attenuation artifacts from the diaphragmatic tissue in inferior wall defects.[4]

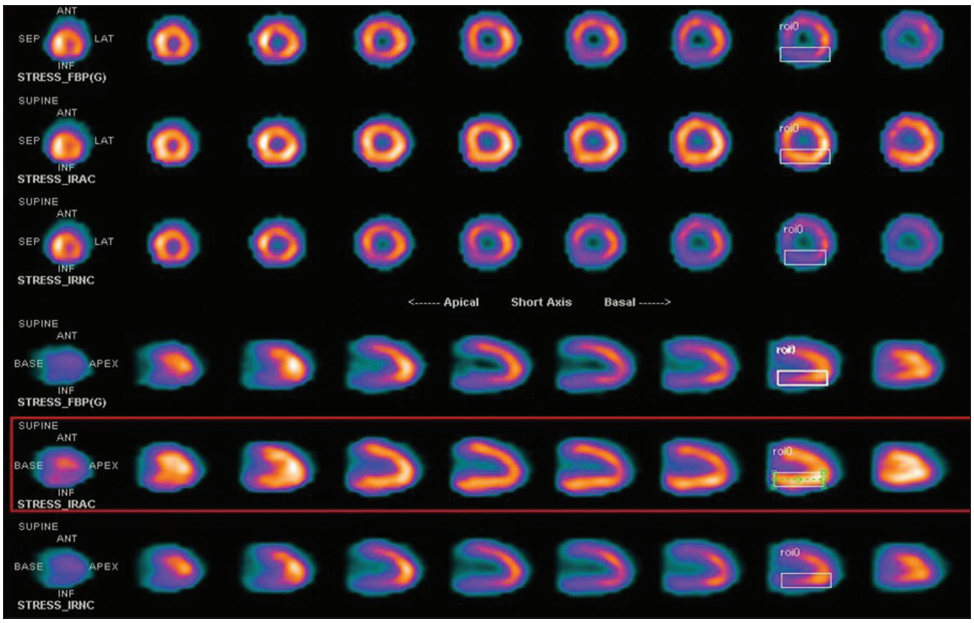

Figure 1: Vertical long axis (VLA) and short axis (SA) slices from myocardial perfusion images of a 66-year-old obese man without AC and with AC. Note the reduce in the inferior wall of the myocardium in the FBP and the IRNC images due to diaphragmatic attenuation, which was corrected on the attenuation compensated (IRAC) images. Also, no difference in the image quality was observed between FBP and IRNC images. Greater image homogeneity was demonstrated with IRAC. FBP, IRAC (CT-based AC), IRNC (CT-based nonAC)

Rest-stress Tc-99m SPECT imaging is a widely used noninvasive technique for the assessment of patients with known or suspected CAD. The low-dose stress is an accepted protocol as per the American Society of Nuclear Cardiology (ASNC) guidelines.[13] This protocol, in selected patients, has several important advantages such as the elimination of radiation dose during rest, investigation time, and subsequent rest imaging. It also enables a more efficient way of working, with consequent cost benefits.[14]

In the current study, the noncardiac mortality rate of 0.02% at 46 ± 2 months follow-up time in 157 patients was found. There was no cardiac mortality. The reasons for this data were considered to be the younger population (median age: 57.4 years) and also because the participants had no known cardiac history.

Gibson *et al*.[15] evaluated 652 patients with a low-to-intermediate probability of CAD who underwent stress-only imaging with a mean follow-up time of 22.3 months. They reported a 0.6% overall cardiac event rate with no cardiac death and only one nonfatal myocardial infarction. Similarly, Gal and Ahmad[16] found a mortality rate of 0.9% at 1-year follow-up in 116 patients after a normal stress-only SPECT. Mathur *et al*.[14] reported a low 0.55% all-cause annual mortality rate with stress-only imaging.

Duvall *et al*. studied all-cause and cardiac mortality in a cohort of 4,910 patients with a normal SPECT MPI study, with a mean follow-up of 40 ± 9 months. The 1-year cardiac mortality was 0.2% in the stress-only group and 0.1% in the rest-stress group; there was no significant difference between the groups after controlling the confounding variables for both all-cause mortality and cardiac mortality.[17]

In obese patients, MPI study can be particularly challenging because of excessive attenuation from soft tissue and also due to the greater distance of the heart. The diagnostic accuracy of noninvasive imaging is often limited by poor exercise tolerance, poor acoustic windows, attenuation artifact, and/or poor signal-to-noise ratios.[18]

In our study, the BMI values were compared to the values of AC (IRAC) and NC (FBP) in myocardial perfusion images. Statistically significant differences were found in the subjective image reconstructed between FBC and IRAC in obese and nonobese patients ($P < 0.05$).

Several studies have shown that AC is beneficial in both obese and nonobese patients, and that the benefit is greater in patients with BMI.[3,19,20]

Recent studies have shown that diagnostic accuracy of non-attenuation corrected SPECT is lower in patients with BMI >30. AC improved the specificity and diagnostic accuracy in these patients.[3,20,21] It is also suggested that AC enhances the specificity and normalcy in nonobese patients.[3]

In our study, images reconstructed by FBP and OSEM of obese and nonobese patients of all other studies were

evaluated in MPI. Statistically significant differences were found in the subjective image reconstructed between FBC and IRAC in obese and nonobese patients ($P < 0.05$). Thus, CT-based iterative reconstruction images were markedly improved in the diaphragmatic attenuation on inferior wall of all patients.

The iterative reconstruction methods reduce the artifactual decrease in activity caused by attenuation so that the image appearance more accurately represents the actual activity in the myocardium, leading to an improved image quality. Iterative reconstruction methods provide more quantitative imaging information and incorporate the effects of noise, counting statistics, missing data, and attenuation.

Masood *et al*. demonstrated that CT-based AC of SPECT using a dual-head SPECT/CT device improved the overall diagnostic accuracy of MPI and is therefore well-suited for routine clinical use.[22] In a multicenter trial, Johansen *et al*.[23] have shown that AC resulted in a significant diagnostic alteration in approximately 10% of the patients, leading to a change in reading from abnormal to normal predominantly because of the modifications in the interpretation of the right coronary artery territory.

In MPI, iterative reconstruction reduces the false positive rate caused by scatter, depth-dependent detector responses (resolution), and attenuation from the myocardium, breast, and diaphragm.

Guibbini *et al*. demonstrated the effect of attenuation and scatter correction on infarct size and on residual peri-infarctional ischemia measurements using semiquantitative approaches, in comparison to NC studies. Their study showed that without AC, the scar size would be systematically overestimated.[24]

There are also suggestions that even without AC, image quality is superior when iterative reconstruction rather than FBP is used.[25]

Narayanan *et al*. demonstrated that iterative reconstruction provides better performance than FBP reconstruction for the overall detection of CAD and the localization of perfusion defects in the three arterial territories. AC may also provide added benefit in stress-only and in non-ECG-gated protocols because it is more challenging to differentiate a perfusion defect from attenuation by means of these protocols.[26]

Infinia Hawkeye 4 SPECT/CT camera with a low-dose CT (140 kVp and 2.5 mA) provides only AC and anatomical localization rather than complete morphological evaluation. With typical rest/stress radiation dosing using technetium being divided into 1:3 ratio, stress-only imaging reduces radiation exposure by 25%.[27,28]

This study has some limitations. Its design is retrospective. The CT image quality of Infinia Hawkeye 4 SPECT/CT camera is limited, which was used for AC and anatomical correlation.

Conclusion

Increased attenuation of the inferior wall was detected in male patients and those with higher BMI. AC with OSEM iterative reconstruction significantly improves the diagnostic accuracy of stress-only SPECT MPI in patients, but the improvements are significantly greater in obese patients. Stress-only SPECT imaging with AC provides shorter and lower radiation exposure in low-risk cardiac events. To conclude, it can be said that the method of iterative reconstruction imaging is helpful in differentiating myocardial ischemia from diaphragm attenuation; thus, it eliminates subsequent rest imaging and reduces radiation dose, unnecessary imaging time, and radiopharmaceutical doses, and it may also prevent unnecessary cardiac catheterizations.

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