The effect of attenuation correction on image quality in single photon emission computed tomography

Nina Frelih[1], Luka Ležaič[1], Janez Žibert[2], Sebastijan Rep[1,2]*

1 Department for Nuclear Medicine, University Medical Centre Ljubljana, Slovenia
2 University of Ljubljana, Faculty of Health Sciences, Medical Imaging and Radiotherapy Department, Ljubljana, Slovenia

* **Corresponding Author:** Sebastijan Rep **E-mail:** sebastijan.rep@guest.arnes.si

ABSTRACT

Objective: Attenuation has a significant influence on data and consequently on image quality. Attenuation correction corrects the weakening of the gamma photons in various depths. Non-diagnostic, low-dosage CT is usually used for attenuation correction when images are taken with a SPECT/CT. The purpose of the study was to determine the influence of attenuation correction in SPECT/CT on image quality in NEMA body phantom analysis in different background/sphere ratios.

Material and Methods: The NEMA IEC Body Phantom was filled with isotope technetium-99m (99mTc), with a different ratio between the phantom background and spheres. The images were reconstructed using filtered back projection (FBP), non-corrected iterative reconstruction (IR), and iterative reconstruction using computer tomography for attenuation correction (CT-AC). The average number of counts in the background and in all six spheres was measured. This was followed by a comparison of the contrast in images that were reconstructed using different methods.

Results: The average number of counts in sphere increased as we increased the activity concentration ratio between the background and sphere. Statistical analysis showed that contrast is significantly divergent between different methods of reconstruction.

Conclusion: The use of iterative reconstruction with CT-AC improves the contrast and image quality compared to iterative reconstruction and FBP.

Key words: SPECT/CT, iterative reconstruction, attenuation correction, filtered back projection, contrast

INTRODUCTION

Single photon emission computed tomography (SPECT) is a nuclear medicine tomographic imaging technique using gamma photons. In tomography, the camera rotates around the patient and a large number of images are taken at different angular projections ([1]). An issue in imaging is caused by the attenuation of photons, the resulting artefacts and inhomogeneity, and thus a deterioration in the quality of SPECT. To improve image quality, it is important that SPECT images are corrected for attenuation. There are different ways to correct attenuation. In some cases, a SPECT gamma scanner may be built to operate with a CT scanner (SPECT/CT). The function of CT is to ensure the improved localisation and definition of organs. In addition to anatomical data, CT images also serve to correct the attenuation of emission data ([1-3]). It is necessary to be aware that CT also causes additional radiation exposure to the patient. It is therefore necessary to carefully plan and optimise the SPECT/CT imaging protocols ([1]).

Attenuation has a significant impact on data and thus image quality. Photon attenuation means a decrease in the number of events from the body. It is a loss of photons due to interactions between photons and electrons. The energy of a photon is converted into the energy of an electron during absorption. Attenuation on reconstructed images causes artefacts and inhomogeneity, resulting in false positive results or negative results. It is therefore important that SPECT images are corrected for attenuation ([1-3]). In SPECT, attenuation depends on photon energy, tissue composition and density ([1, 4]).

Due to the lungs, there is less attenuation in the chest than in the abdomen. Bones have slightly greater attenuation than soft tissues. Due to attenuation effects, there is a minimum of accumulation of activity in the centre of the image. The result of greater attenuation from inside the body is reduced intensity in tomograms for these areas (**4**).

Non-diagnostic, low-dose CT (10-40 mA) is used to correct attenuation, making images of appropriate quality for their purpose (**1**). CT imaging follows immediately after SPECT acquisition (**5**). With CT imaging, we obtain transmission maps that are used to correct attenuation on SPECT data. The efficiency of AC depends on the quality of the transmission folders. In reconstructed images, artefacts resulting from inconsistencies in CT data and emission data are common. Artefacts are most often seen in areas where there is a great deal of movement (movement due to respiration) and where there are major changes in attenuation coefficients (**6, 7**). Poorer image quality is therefore caused by metal implants and patient movement during CT acquisition. In addition to movement and respiration, the cause of discrepancy between emission and transmission imaging the table which is bent when it is driven into the gantry (**8**). CT imaging takes much less time than SPECT, resulting into a time mismatch. This poses a problem, especially when imaging the chest because the heart and lungs are moving organs. This temporal mismatch can lead to unwanted artefacts on attenuation-corrected images, which can lead to the misinterpretation of results (**3**). To exclude artefacts due to AC, it is important to always check both corrected and uncorrected images (**1, 3**). The anatomical accuracy of image fusion should be checked before interpreting corrected scintigrams (**5**).

The effect of attenuation correction on image quality in SPECT/CT have already been studied by Yong-Soon et al. who evaluated phantom scans (**9**), Sung et al. who explored the effect on different phantoms (**10**) and Schulz et al. who also performed a patient study (**11**) and various studies evaluating the image quality in myocardial perfusion scintigraphy (**12-14**).

The purpose of our study was to systematically perform SPECT/CT imaging of NEMA body phantom with eight different background/sphere activity concentration ratios, which has not been done by previous authors, and to determine the effect of attenuation correction on image contrast. With our research we aimed to confirm that the use of CT-AC improves the visualization of smaller spheres at different background/sphere ratios.

MATERIAL AND METHODS

We used an experimental method, phantom imaging and research with image processing on SPECT/CT. Imaging was performed on a Siemens Symbia T2 gamma camera and included dual-slice spiral computed tomography. We used NEMA IEC Body Phantom (NEMA 2012/IEC 2008) for imaging, which contains six spheres of different sizes. The phantom was filled with the isotope technetium-99m (99mTc). Phantom imaging was performed eight times, each with a different ratio of specific activity between the spheres and phantom background. The phantom background was filled each time with approximately 100 MBq of 99mTc. The ratio in specific activity between the background of the phantom and the spheres in the phantom was thus 1:2, 1:3, 1:4, 1:5, 1:6, 1:7, 1:8 and 1:9 (Table 1). Imaging was performed immediately after the phantom was filled. The imaging protocol is shown in the Table 2. The images were processed using an Oasis hybrid reconstruction application. The quality of the images was then compared. Each image was reconstructed using FBP algorithm (Butterworth reconstruction filter, order 4 and cutoff 0.75) IR algorithm (4 iterations and 10 subsets) IR algorithm with CT-AC (4 iterations and 10 subsets). After reconstruction we marked regions of interest (ROI) around the spheres and in the background and measured the average number of counts as demonstrated in Figure 1. In each reconstructed image, we marked all six spheres with diameters of 10 mm, 12 mm, 16 mm, 22 mm, 28 mm and 36 mm, and the background in six different places. A circle diameter of 20 mm was used to measure number background counts. Contrast (C) was calculated as a relative difference between foreground and background by using the equation:

$$C = \frac{A - B}{B}$$

where C represents the calculated contrast, A represents the average number of counts in the spheres of the NEMA phantom and B represents the average number of counts in the selected background region of the NEMA phantom. To determine the difference in average number of counts in spheres and the contrast in all three reconstruction methods we performed repeated measures ANOVA. We tested the pair difference between image contrast in the Matlab program. Because the data were not normally distributed, we performed the Wilcoxon signed rank test. The data were statistically processed in Statistical Package for the Social Sciences (SPSS) program, version 22. A significance of $p < 0.05$ was used for all the tests.
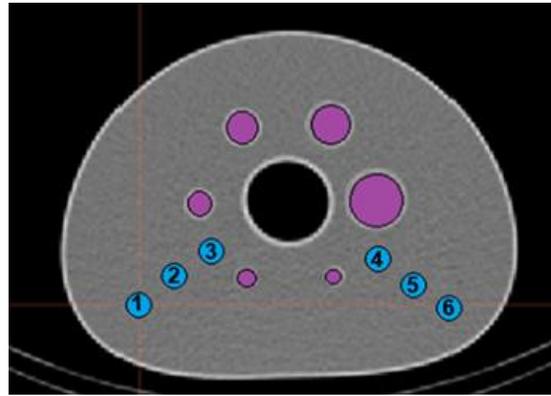
Table 1: Activities of 99mTc expressed in MBq/L in spheres and background

Ratio	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9
Background (MBq/L)	10,38	10,27	10,41	10,45	10,03	10,25	10,07	9,91
Spheres (MBq/L)	20,42	31,72	43,06	54,57	62,41	73,93	81,2	91,10

Table 2: The imaging protocol on SPECT/CT.

Number of Views	32
Time per view	20 sec
Zoom	1
Matrix size	128 X 128
Starting angle	0
Degrees of Rotation	180
Rotation Direction	CW
Detectors	Both Detectors
Detectors Configuration	180
Mode	Step and shoot
mAs	25
kV	130

Figure 1: The CT image shown the areas where we marked the ROI to determine the number of average counts in spheres (red) and background (blue) on SPECT/CT.

RESULTS

Figure 2 shows the average number of counts in spheres in all three reconstruction methods. The average number of counts in spheres increases as we increase the activity concentration ratio between the background and spheres.

With repeated measures ANOVA the significant differences in the average number of counts ($p < 0.001$) between FBP reconstruction, IR and IR CT-AC reconstruction were confirmed.

Contrast of FBP, IR and IR CT-AC reconstructions in all six phantom spheres for all radioactivity concentration ratios are given in Figure 3.

When comparing the contrast between IR CT-AC, IR and FBP reconstructed images (Figure 4), we found that larger spheres (> 12 mm) were well visible in all reconstructions but the difference was observed in smaller spheres and in a low activity-to-sphere ratios. The smallest 10 mm sphere can be seen in IR CT-AC reconstructed images at the activity concentration ratio of 1:9, but is not visible in IR or FBP reconstructed images.

The 12 mm sphere is seen in IR CT-AC images at the ratios of $\geqslant$ 1:6, in IR images at ratio $\geqslant$ 1:7 and in FBP images at ratios of $\geqslant$ 1:8.

An analysis of the contrast between the phantom spheres and background with repeated measures ANOVA showed a statistically significant difference between different reconstruction methods ($p < 0.001$). We also compared two reconstructions and determined the significance of the difference using the Wilcoxon matched-pairs signed rank test. A statistical analysis between IR CT-AC vs FBP, IR CT-AC vs IR and IR vs FBP reconstruction showed $p < 0.001$, which means that the contrast and thus image quality are significantly different between the two reconstructions. Figure 5 shows the contrast for all reconstructions and the subtraction of images. The figures (A, B and C) represent the contrast of all the scans, with eight different ratios, as well as the contrasting of the six spheres. Black colour represents a negative contrast and a contrast of less than 10%, which means that such lesions cannot be seen. Lighter colour represents a positive contrast; the lighter or whiter the field, the better is contrast. White represents the contrast, higher than 65%.

The last figure (D) is the contrast subtraction of two different reconstructions, where the dark fields mean there is not much difference between the two reconstructions; the brighter the fields, the greater the difference in contrast.
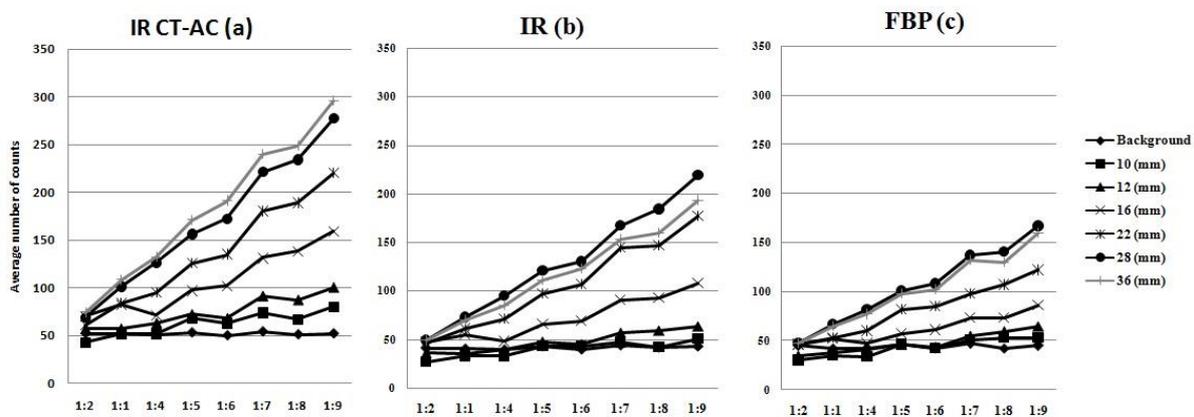

Figure 2: The effect of different reconstruction algorithms with and without AC on number of average counts in background and different spheres for eight radioactivity concentration ratios.
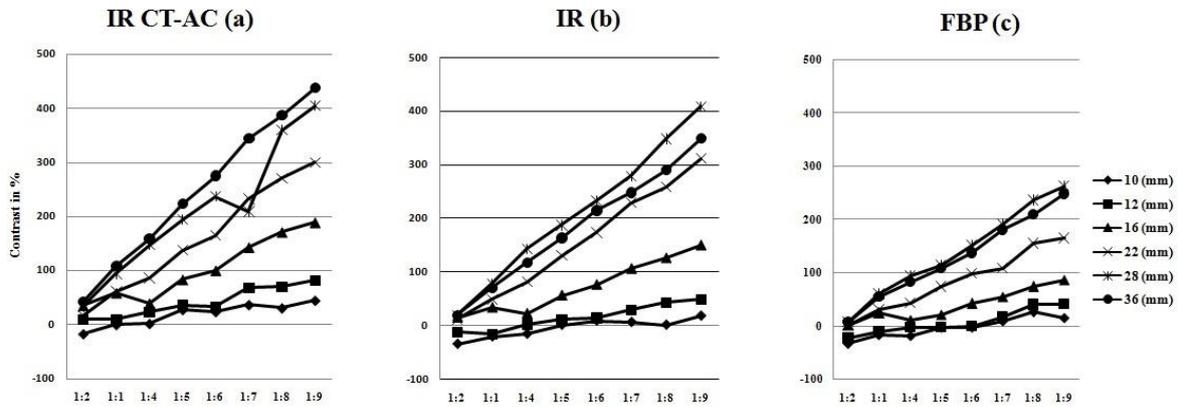
Figure 3: Measurements of contrast expressed in % in all six NEMA phantom spheres for all radioactivity ratios reconstructed with iterative reconstruction corrected with CT-AC (a), iterative reconstruction (b), FBP (c).
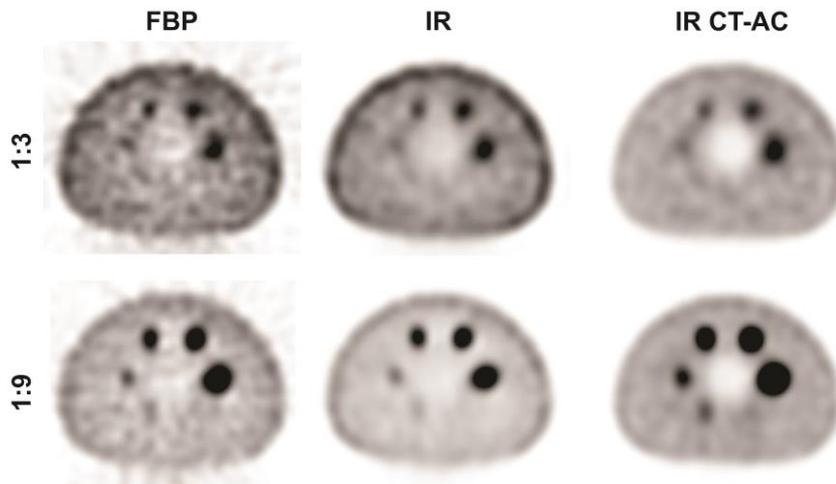

Figure 4: NEMA body phantom, filled in the radioactivity concentration ratio background/sphere1:3 (top row), 1:9 (bottom row) and reconstructed FBP, IR and IR CT-AC.
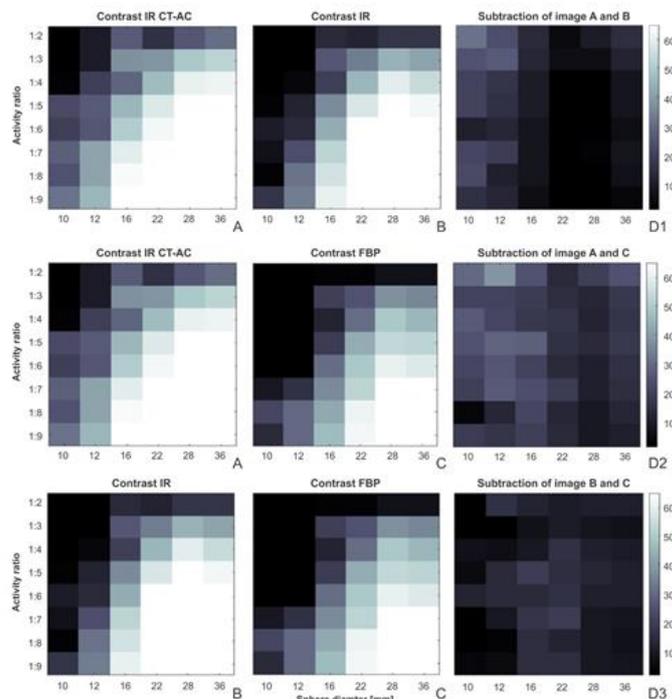

Figure 5: Contrast of iterative reconstruction with CT-AC (A) ,iterative reconstruction (B) and FBP (C). The subtraction of figure A vs B is figure D1, A vs C is figure D2 and B vs C is D3. Black colour on figure A, B and C represents a negative contrast and a contrast of less than 10%, which means that such lesions cannot be seen. Lighter colour represents a positive contrast. White colour represents the contrast, higher than 65%. The figure C represent the contrast subtraction of two different reconstructions, where the dark fields mean that there is not much difference between the two reconstructions; the brighter the fields, the greater the difference in contras

DISCUSSION

The ratio of activity concentration between the background and sphere has no effect on the average number of counts in the background because we always filled the background with comparable activity. In FBP and IR due to the influence of attenuation, the average number of counts on the outside of the phantom is greater and falls towards the middle of the phantom. Due to attenuation, the background is inhomogeneous. CT-AC corrects the effect of attenuation, making the average number of counts more even over the entire background of the phantom and the line almost straight.

The size of the sphere and background-sphere activity concentration ratio affect the average number of counts and thus the contrast of the image. We showed that the average number of counts and thus the contrast of the image increases with the size of the sphere and with a larger ratio of activity between the background and the sphere in all three methods of reconstruction. A larger sphere means a larger average number of counts, i.e. better contrast and image quality . The SPECT/CT limitation is the relatively poor spatial resolution of the detector system, which makes it impossible to visualize small spheres ($\leqslant$ 12 mm) with FBP and IR at lower ratios ($\leqslant$ 1:6). With IR CT-AC, the visualization of the spheres is improved, but for small spheres at lower ratios it is not displayed ($\leqslant$ 1:7).

The reason for the negative contrast in smaller spheres is higher number of average counts in background obtained from ROIs placed over the entire diameter of the NEMA body phantom. Due to attenuation, the number of average counts in FBP and IR reconstructions was higher than the number of average counts in spheres, especially in spheres $\leqslant$ 12 mm and in the ratio $\leqslant$ 1:5.

When comparing the contrast between IR CT-AC and FBP reconstructed images, we found that the largest spheres were well visible in both reconstructions. The largest difference was seen in smaller spheres and in a low activity-to-sphere ratio. In clinical practice, this means that minor lesions on FBP reconstructed images can be overlooked. There is also a major difference in the contrast of the images between the two reconstructions at a background-sphere ratio of 1:2.

When comparing the contrast between IR CT-AC reconstructed images and IR, we found that the most significant difference in contrast is at small spheres. With large spheres and with a high background-sphere ratio, there is not much difference in the contrast of the image between the two reconstructions, which means that we will see the spheres well in both images.

FBP and IR have a similar contrast in small lesions at a low ratio and in large lesions at a high ratio. We will not see the smallest sphere on any reconstruction, while we will see large spheres on both. A difference occurs in the central part, in medium-sized spheres. The contrast of the image is better in IR.

Based on all the results, we can conclude that the images using IR CT-AC reconstruction have better image quality than uncorrected images. Several studies have been conducted where similar results have been obtained. One such study was conducted by Yong-Soon et al. who came to the same conclusions (9). They concluded that image quality was improved using CT-AC reconstruction and that CT dose had no significant effect on image quality. It is thus not necessary for the CT dose to be higher if the CT serves us only for localisation and AC. When CT is needed for diagnostic purposes, the dose may be increased.

Sung et al. came to similar conclusions in their study (10). They compared the contrast before and after the use of CT-AC on the NEMA IEC Body PhantomTM and the Jaszczak phantom, and the spatial resolution using the NEMA SPECT Triple Line Source PhantomTM. Contrast was improved by using IR CT-AC on both phantoms, as well as spatial resolution. They concluded that SPECT/CT provides significantly better image quality than SPECT, while contrast and spatial resolution were improved.

Schulz et al. found that CT-AC corrects distribution inhomogeneity due to attenuation, but that inconsistencies between SPECT and CT images can lead to erroneous results. It is thus very important to check the accuracy of image fusion in each patient (11). They conclude that further research would be needed to fully investigate the impact of CT-AC.

Most researchers have observed the effect of attenuation correction using CT on myocardial perfusion scintigraphy and all have come to similar conclusions.

Malkerneker et al. described that CT-AC in myocardial perfusion scintigraphy improves image quality and increases diagnostic accuracy (12). Pazhenkottil et al. found that CT-AC adds prognostic value and provides higher left ventricular imaging homogeneity in healthy subjects and increases diagnostic accuracy (13). The results of this study showed that correction of attenuation successfully reduces the number of false-positive results, especially with CT.

Research conducted by Fricke et al. showed that myocardial perfusion scintigraphy using CT-AC provides more accurate images than an examination without the use of correction (14).

According to some data, attenuation-uncorrected images are also of better quality when using IR compared to FBP reconstruction (15). Our results are comparable; the image quality was improved IR relative to FBP reconstruction. Also, a study conducted by Narayanan et al. confirms that IR provides better efficacy for localising perfusion defects and detecting coronary artery disease (CAD) than FBP reconstruction (16). It is best to use IR in combination with AC for the best CAD detection efficiency.

In perfusion myocardial scintigraphy, an incorrect result can lead to an invasive examination (coronary angiography), which is unacceptable. Thus, the correction of attenuation is extremely important and its use is recommended by the American Society of Nuclear Cardiology and the Society of Nuclear Medicine (17).

CONCLUSION

Based on our results, the use of iterative reconstruction with CT-AC improves the contrast and image quality relative to iterative reconstruction and FBP. In clinical practice, tumours and various lesions are of all possible shapes and sizes. Thus,

the use of CT-AC reconstruction is recommended for all examinations. Because the use of CT to correct attenuation may increase the radiation exposure of patients, imaging protocols should be carefully designed.

Author contributions: NF, LL, JZ, SR; Literature search and study design, experimental aplications **SR;** Writing article and revisions

Conflict of interest: The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. This research did not receive and specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Ethical issues: All authors declare originality of research.

REFERENCES

1. Ziegler SI, Dahlbom M, Sibylle I, et al. Diagnostic Nuclear Medicine. 2nd ed. Berlin: Springer, 2006.

2. James A Patton, Timothy G Turkington. SPECT/CT Physical Principles and Attenuation Correction. J Nucl Med Technol 2008;36: 1–10. doi: 10.2967/jnmt.107.046839

3. Magdy M K Ed. Basic Sciences of Nuclear Medicine. London: Springer, 2011.

4. Dale L. Bailey, Anthony Parker J. Nuclear Medicine in clinical diagnosis and treatment. 3rd ed. Churchill Livingstone, 2004.

5. Mariani G, Flotats A, Israel O, Kim EE, Kim E.E, Kuwert T. Clinical Applications of SPECT/CT: New Hybrid Nuclear Medicine Imaging System. Wien: Nuclear Medicine Section International Atomic Energy Agency, 2008.

6. Grosser OS, Kupitz D, Ruf J, et al. Optimization of SPECT-CT Hybrid Imaging Using Iterative Image Reconstruction for Low-Dose CT: A Phantom Study. PLoS ONE 2015; 10(9). doi.org/10.1371/journal.pone.0138658

7. Suzuki A, Koshida K, Matsubara K. Effects of Pacemaker, Implantable Cardioverter Defibrillator, and Left Ventricular Leads on CT-Based Attenuation Correction. J Nucl Med Technol 2014; 42: 37–41. doi: 10.2967/jnmt.113.133736

8. Apostolopoulos D, Savvopoulos C. What is the benefit of CT-based attenuation correction in myocardial perfusion SPET?. Hell J Nucl Med 19 2016;(2):89-92. doi: 10.1967/s0024499100360

9. Yong-Soon P, Woo-Hyun K, Dong-Oh S, et al. A Study on the Change in Image Quality before and after an Attenuation Correction with the Use of a CT Image in a SPECT/CT Scan. Journal of the Korean Physical Society 2012; 61 (12): 2060-2067. doi:10.3938/jkps.61.2060

10. Sung WC, Yong JS, Jin EK, Jae SL, Dong SL. Evaluation of image quality using CT attenuation correction in SPECT/CT. J Nucl Med 2013;54(2). supplement 2 2621

11. Schulz V, Nickel I, Nömayr A, et al. Effect of CT-based attenuation correction on uptake ratios in skeletal SPECT. Nuklearmedizin 2007; 46(1):36-42. doi: 10.1055/s-0037-1616624

12. Malkerneker D, Brenner R, Martin WH, et al. CT-based attenuation correction versus prone imaging to decrease equivocal interpretations of rest/stressTc-99m tetrofosmin SPECT MPI. J Nucl Cardiol 2007;14:314–323. doi: 10.1016/j.nuclcard.2007.02.005

13. Pazhenkottil AP, Ghadri JR, Nkoulou RN, et al. Improved Outcome Prediction by SPECT Myocardial Perfusion Imaging After CT Attenuation Correction. J Nucl Med 2011;52 (2):196–200. doi: 10.2967/jnumed.110.080580

14. Fricke E, Fricke H, Weise R, et al. Attenuation Correction of Myocardial SPECT Perfusion Images with Low-Dose CT: Evaluation of the Method by Comparison with Perfusion PET. J Nucl Med 2005;46:736–744.

15. Tamam M, Mulazimoglu M, Edis N, et al. The Value of Attenuation Correction in Hybrid Cardiac SPECT/CT on Inferior Wall According to Body Mass Index. World J Nucl Med 2016;15(1):18–23. doi: 10.4103/1450-1147.167586

16. Narayanan MV, King MA, Pretorius PH, et al. Human-Observer Receiver-Operating-Characteristic Evaluation of Attenuation, Scatter, and Resolution Compensation Strategies for 99m Tc Myocardial Perfusion Imaging. J Nucl Med 2003;44:1725–1734.

17. Thompson JD, Hogg P, Manning DJ, et al. A free-response evaluation determining value in the computed tomography attenuation correction image for revealing pulmonary incidental findings: a phantom study. Acad Radiol 2014;21(4):538–545. doi: 10.1016/j.acra.2014.01.003