A Free-response Evaluation Determining Value in the Computed Tomography Attenuation Correction Image for Revealing Pulmonary Incidental Findings:

A Phantom Study

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Rationale and Objectives: The purpose of this study was to compare lesion-detection performance when interpreting computed tomography (CT) images that are acquired for attenuation correction when performing single photon emission computed tomography/computed tomography (SPECT/CT) myocardial perfusion studies. In the United Kingdom, there is a requirement that these images be interpreted; thus, it is necessary to understand observer performance on these images.

Materials and Methods: An anthropomorphic chest phantom with inserted spherical lesions of different sizes and contrasts was scanned on five different SPECT/CT systems using site-specific CT protocols for SPECT/CT myocardial perfusion imaging. Twenty-one observers (0–4 years of CT experience) searched 26 image slices (17 abnormal, containing 1–3 lesions, and 9 normal, containing no lesions) for each CT acquisition. The observers marked and rated perceived lesions under the free-response paradigm. Four analyses were conducted using jackknife alternative free-response receiver operating characteristic (JAFROC) analysis: (1) 20-pixel acceptance radius (AR) with all 21 readers, abbreviated to 20/ALL analysis, (2) 40-pixel AR with 21 readers (40/ALL), (3) 20-pixel AR with 14 readers experienced in CT (20/EXP), and (4) 20-pixel AR with 7 readers with no CT experience (20/NOT). The significance level of the test was set so as to conservatively control the overall probability of a type I error to <0.05.

Results: The mean JAFROC figure of merit (FOM) for the five CT acquisitions for the 20/ALL study were 0.602, 0.639, 0.372, 0.475, and 0.719 with a significant difference in lesion-detection performance evident between all individual treatment pairs ($P < .0001$) with the exception of the 1-2 pairing, which was not significant (these differed only in milliamp seconds). System 5, which had the highest performance, had the smallest slice thickness and the largest matrix size. For the other analyses, the system orderings remained unchanged, and the significance of FOM difference findings remained identical to those for 20/ALL, with one exception: for 20/EXP analysis the 1-2 difference became significant with the higher milliamp seconds superior. Improved detection performance was associated with a smaller slice thickness, increased matrix size, and, to a lesser extent, increased tube charge.

Conclusions: Protocol variations for CT-based attenuation correction (AC) in SPECT/CT imaging have a measurable impact on lesion-detection performance. The results imply that z-axis resolution and matrix size had the greatest impact on lesion detection, with a weaker but detectable dependence on the product of milliamp and seconds.

Key Words: CT attenuation correction image; CT acquisition parameters; lesion detection; anthropomorphic chest phantom; JAFROC.

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Attenuation correction (AC) has become necessary in myocardial perfusion imaging (MPI) because of the likelihood of photon attenuation artifacts. In addition to a general reduction of photon counts in larger patients, localized photon attenuation artifacts typically caused by diaphragmatic attenuation in larger men and breast attenuation in larger women (1,2) can cause difficulties in interpretation. Misinterpretation could lead to unnecessary invasive intervention, such as coronary angiography. This type of error is clinically unacceptable, and a high-quality attenuation map is recommended to correct for these patient-induced artifacts (3). For these reasons, AC is recommended by the American Society of Nuclear Cardiology and Society of Nuclear Medicine for MPI studies (4).

AC was initially performed using radionuclide-based transmission images but has been superseded by an x-ray computed tomography (CT)–based technique (5–7).

In comparison to a radioactive line source, CT-based AC has improved the quality of the attenuation map because of better spatial resolution, increased photon flux, and no cross talk from different radionuclide γ-ray energies. As a result, MPI studies have seen improvements in diagnostic accuracy (8,9).

Although the usefulness of CT-based AC is clear, there is controversy regarding what must be done about the incidentally produced low-resolution CT images that are the basis of AC.

In the United Kingdom, regulations dictate that a clinical evaluation and record must be made for every exposure (10). The implication here is that all image information should be reviewed, regardless of the reason for exposure (ie, AC and not a diagnostic quality scan). However, the typically low quality of images produced for AC in single photon emission computed tomography/computed tomography (SPECT/CT) means that it is not clear whether this could be counterproductive. To further complicate this, the diagnostic quality of these images is also liable to significant variation because of the diversity of CT parameters used for an AC acquisition in different SPECT/CT systems. Despite variation in the acquisition, the reliability of attenuation maps provided by CT units has been found to be independent of both tube charge (milliamp seconds) (11) and tube rotation speed (12). Furthermore, a static phantom study of the low-resolution CT images produced by a single SPECT/CT system for AC has reported that milliamp seconds had no impact on an observer's ability to detect certain simulated lesions (13).

Some retrospective clinical work has been done to evaluate the diagnostic suitability of these low-resolution images; Goetze et al. (14) studied 200 consecutive patients undergoing attenuation-corrected MPI using CT-based AC in a single SPECT/CT system. The review of these coincidentally acquired low-resolution images revealed 234 extracardiac abnormalities in 119 patients; 15 previously undiscovered incidental findings were categorized as having major significance, requiring either further testing or follow-up. An expert in CT and a resident in nuclear medicine with no formal CT training completed this retrospective review, and the results described the consensus opinion. Based on the consensus opinion, the authors recommended routine assessment of these low-resolution images. However, no receiver operating characteristic (ROC) study was completed and their study was confined to a solitary SPECT/CT system while in practice there is considerable variation in acquisition parameters and other device characteristics between SPECT/CT systems in clinical use. The present study investigates the impact of the CT acquisition parameters used in five SPECT/CT systems in the United Kingdom.

MATERIALS AND METHODS

Image Acquisition

Because it would not be desirable from ethical and practical considerations to image enough patients in all five modalities to generate sufficient numbers of normal and abnormal cases for the observer study, a phantom study was indicated. Phantom simulation allows the production of reliable system-matched images without concerns over radiation dose.

Spherical simulated lesions with diameters 3, 5, 8, 10, and 12 mm and densities −800, −630, and +100 Hounsfield units (HU), for a total of 15 inserted lesions (some diameter–density combinations were repeated) which were manually inserted in 17 transaxial slices in an anthropomorphic chest phantom (*Lungman N1 Multipurpose Chest Phantom; Kyoto Kagaku Company Ltd, Japan*) representing a 70-kg man. The lesions were composed of urethane (−800 and −630 HU) and a combination of polyurethane, hydroxyapatite, and a urethane resin (+100 HU). This resulted in 17 abnormal image slices, each containing 1–3 simulated pulmonary lesions and 9 normal slices, that is, containing no lesions. The phantom was scanned on a dedicated diagnostic quality multidetector CT (MDCT) scanner, not to be confused with CT units in the SPECT/CT systems, which were the subject of the comparison study. The MDCT images provided a lesion-reference map that would act as the truth (gold standard) for the observer performance study. The high-resolution MDCT scan was repeated at the end of the SPECT/CT imaging, described next, to ensure that lesion positions had not changed.

All images for the observer study were produced from a single CT acquisition of the phantom from each SPECT/CT system using site-specific CT acquisition protocols, Table 1, appropriate to a 70-Kg man. The variation in CT acquisition parameters and estimated CT Dose Index (CTDI) listed in Table 1 is representative of general practice in the United Kingdom. The variation in slice thicknesses gave rise to a differing number of axial CT slices, but each acquisition covered the full length of the phantom. Four SPECT/CT systems (labeled 1–4) used low-resolution CT systems from the same manufacturer, and the fifth (labeled 5) used a CT system capable of producing diagnostic quality images from a different manufacturer, which was used as a backup to the dedicated diagnostic CT system in that imaging facility.